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AN INVESTIGATION OF ENVIRONMENTAL FACTORS AFFECTING THE NEAR-BOTTOM CURRENTS IN THE MONTEREY SUBMARINE CANYON

by

Ingmar Joel Njus

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AN INVESTIGATION OF ENVIRONMENTAL FACTORS AFFECTING THE NEAR-BOTTOM CURRENTS IN THE MONTEREY SUBMARINE CANYON

By

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Lieutenant, United States Navy
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requirements for the degree of

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ABSTRACT

Continuous bottom current measurements were taken in the head of Monterey Submarine Canyon in water depths ranging from 80 to 110 fathoms utilizing an in situ Savonius Rotor current measuring system placed approximately 40 feet above the bottom. Concurrent wind, wave, and tidal data were collected with the current measurements. Basic statistical parameters and power spectra were then computed for each time series obtained.

Current speeds in excess of one knot were measured, with the current direction being predominantly along the canyon axis. Water temperature, current speed and direction all exhibit cyclic fluctuations of a periodicity equal to that of the semidiurnal tide. Cold, high-speed currents flow up-canyon (landward) on the falling tide while warmer, slower currents flow down-canyon (seaward) on the rising tide. Wind and wave conditions do not appear to have any significant effects on the near-bottom currents.

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I. INTRODUCTION

A. PURPOSE

The purpose of this research was threefold: (1) to measure the velocity of the near-bottom currents in the Monterey Submarine Canyon at a depth of approximately 100 fathoms, (2) to compare the results of these measurements with earlier data, and (3) to attempt to determine to what extent various environmental parameters (such as tides, wind, and waves) influence the near-bottom currents.

This paper presents the results obtained from continuous recording Savonius current meters, placed 40 feet above the bottom in depths ranging from 80 fathoms to 110 fathoms at the head of the Monterey Submarine Canyon, and concurrent observations of wind velocities, wave heights, and tidal fluctuations.

B. BACKGROUND

Although near-bottom currents in submarine canyons have been measured at several locations over the past two decades, the data obtained has been quite variable, and various factors have been suggested as being the primary influence responsible for the current motion.

For example, Stetson (1936), using an Ekman meter, made direct measurements in three canyons on the Georges Bank. He found a maximum current of 0.2 knot at depths of 46 fathoms and 146 fathoms and determined the movements to be tidal in nature.

Currents of 0.5 knot were measured, using an Ekman meter, by Shepard, Revelle, and Dietz (1939) in several canyons off Southern

California at a depth of 50 fathoms (2 meters off of the bottom). They concluded the tide was not a factor of any importance in causing the currents but rather suggested that they were related to internal waves or irregular eddies with vertical axes.

In later investigations of Scripps Canyon, Shepard measured currents as high as 0.5 knot using a Savonius meter four feet off of the bottom in a water depth of 75 fathoms. Possible explanations for the observed currents include surf beat, and the seaward return flow of water carried inshore by swell (Shepard, et al, 1964).

Recent measurements in Monterey Submarine Canyon have been made by Gatje and Pizinger (1965) and Dooley (1968). Gatje and Pizinger, using an Ekman meter, found the maximum current to be 0.8 knot, and Dooley, using a Savonius meter, recorded currents as high as 1.0 knot. Both were working in a depth of about 70 fathoms. Gatje and Pizinger were approximately 16 feet off of the bottom while Dooley was 50 feet off of the bottom. The former concluded the currents were tidal in nature with down-canyon flow on rising tide and up-canyon flow on falling tide. Thus, it appears the bottom currents are a compensatory counter-current for surface tidal motion.

Dooley concluded that only peak speeds show good tidal correlation but that after a few days even this relationship becomes vague. On the one record where Dooley examined the tide, this author finds good agreement with the conclusions of Gatje and Pizinger over the first portion of the record. In addition to a dominant tidal component, with a 12-hour period of oscillation, Dooley also observed several shorter-period oscillations.

In a visual inspection of recent data obtained in Scripps Canyon by Shepard (personal correspondence), the above tidal correlation does not appear to be substantiated except in isolated segments of the records. His observations consist of simultaneous records from at least two points. Readings near the Canyon floor at depths of 550 feet and 672 feet show good correlation. However, concurrent readings near the Canyon floor at 672 feet and just above an inter-canyon ridge (depth 420 feet) show the flow to be in nearly opposing directions.

In all of the above investigations the direction of flow is predominantly along the canyon axes, and of an oscillatory nature with widely varying periods. The magnitudes are generally less than 0.5 knot. Explanations of the driving forces and factors influencing the currents are numerous, and no single theory has been proven or widely accepted, primarily due to the paucity of data concerning this question.

II. REGION OF INVESTIGATION

A. TOPOGRAPHY OF MONTEREY BAY AND SUBMARINE CANYON

Current measurements were obtained in the canyon axis approximately 1.5 miles west of Moss Landing at the head of Monterey Bay. Figure 1. shows the Monterey Bay region and the general bathymetry of the Bay and Canyon.

Monterey Bay is in open communication with the Pacific Ocean and is subject to the oceanic variations. The bottom of the bay is cut by a massive canyon system which extends from the canyon head, less than one mile off the coast at Moss Landing, to a depth of over 1600 fathoms at a point 50 miles to seaward.

The canyon has a V-shaped profile and follows a meandering path. It has two major tributaries. Soquel Canyon enters from the north at a depth of 500 fathoms, and the Carmel Canyon enters from the South at a depth of 1100 fathoms.

Side slopes of the Monterey Canyon range from 5 degrees to 34 degrees. Near the canyon head there are axial gradients up to 8.5 degrees. The slope gradually decreases until at a depth of 400 feet, it has reached a relatively uniform value of close to 2.5 degrees. This slope persists along the curving course of the canyon out to about 5000 feet where there is an increase to over 6 degrees where the canyon cuts through a granite ridge. The slope then declines evenly to 0.5 degree at its seaward limit. (Martin and Emery, 1967).

Cross-sectional views of the canyon at the approximate depths at which measurements were taken are shown in Figure 2 (Shepard and Emery, 1941). The bathymetry of this area is shown in Figure 3.

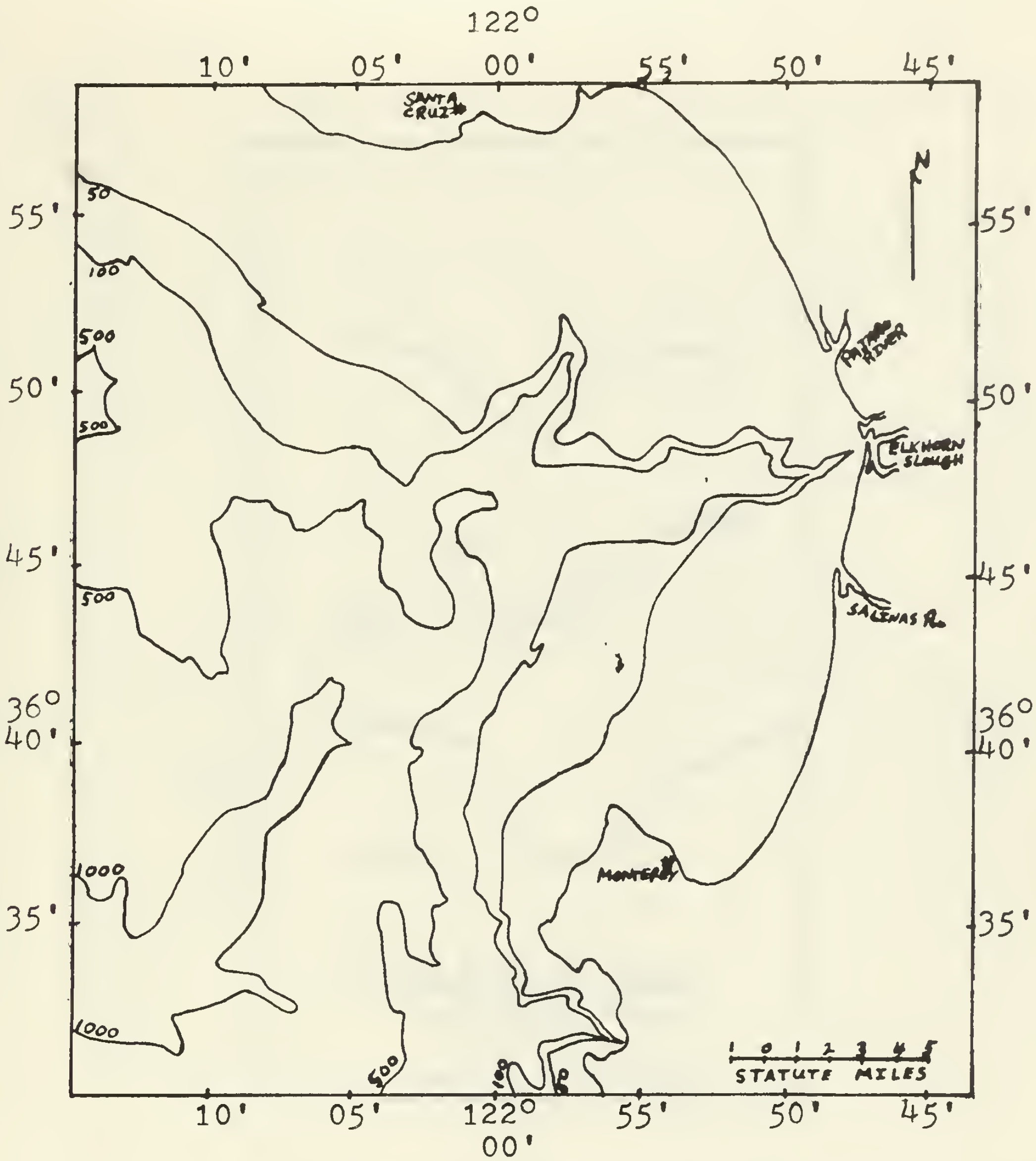


Fig. 1. Monterey Bay (Martin and Emery, 1967).
Contours in fathoms.

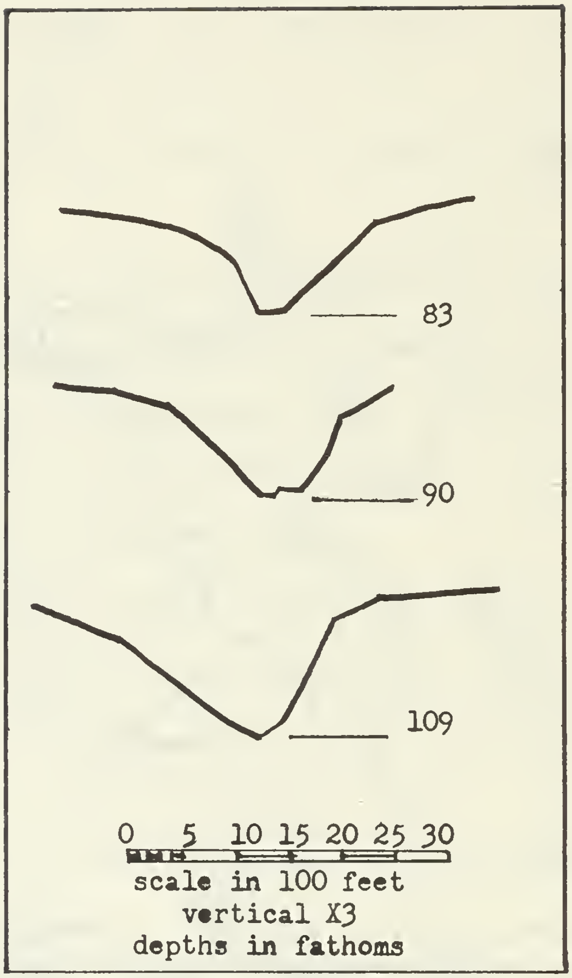


Figure 2. Cross sections at the head of Monterey Canyon (Shepard and Emery, 1941)

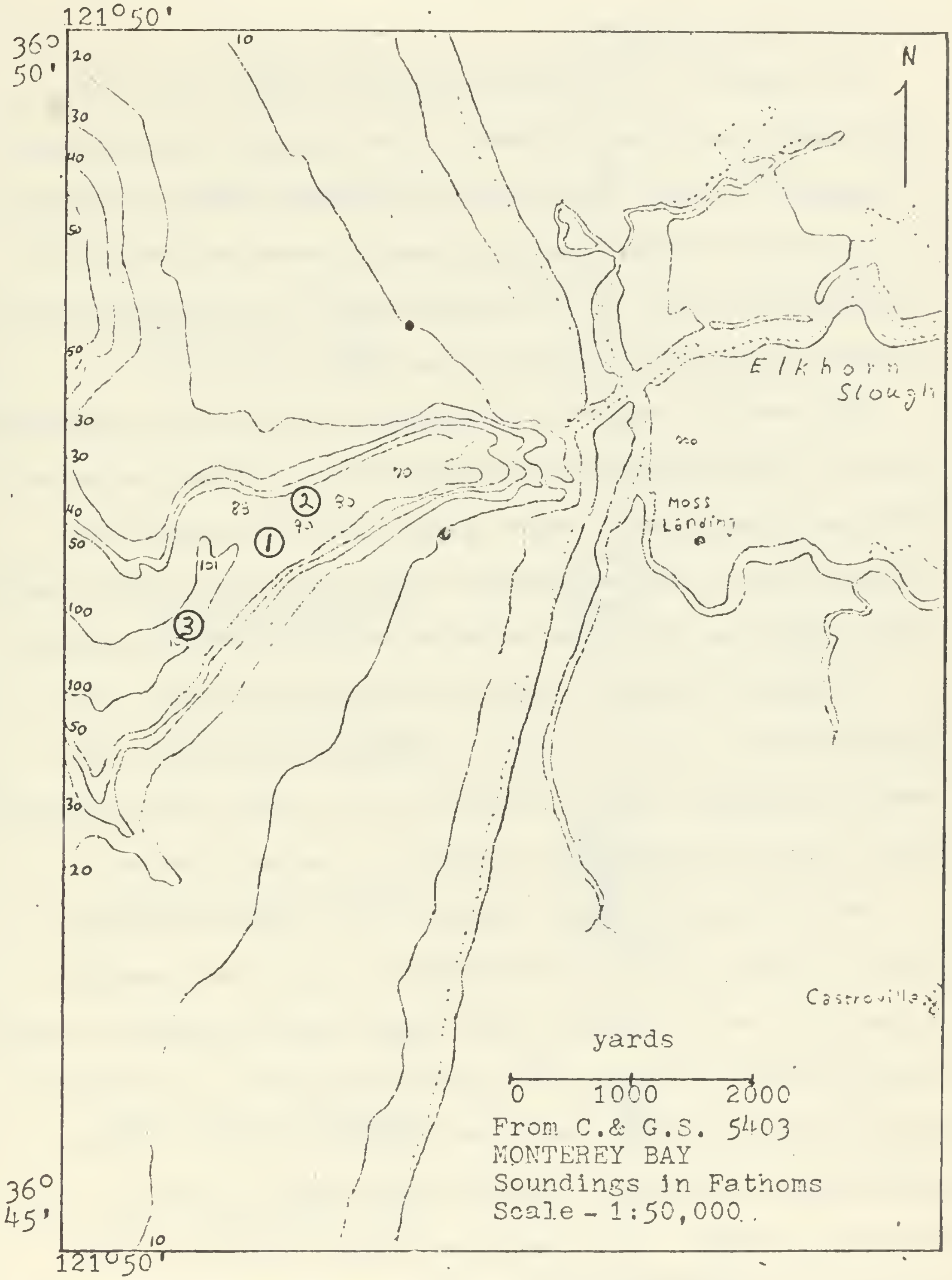


Fig. 3. Bathymetry of the Head of Monterey Submarine Canyon.

III. MEASURING EQUIPMENT AND PROCEDURES

A. THE TAUT-WIRE MOORING

The location of the three moorings established during this investigation are shown in Figure 3. The taut-wire mooring system, as suggested by Dooley (1968), was used for each observation (Figure 4). The Navy 63 foot Hydrographic Research vessel was used in the launching and recovery of all moorings except for one recovery which was made by the Coast Guard Cutter Cape Wash.

Each mooring consisted of an expendable section and a recoverable section. The expendable section consisted of a mooring line and a 500-pound (in air) anchor weight composed of five, cement-filled, five-gallon cans. The mooring line was 30 feet of 3/16 inch polypropylene line connected to the release mechanism of the recoverable section.

It would be desirable to have the meter moored nearer to the bottom; however, due to the rock outcroppings, steep slopes, and unknown topographic features in the area, the longer mooring line was used to reduce the possibility of damage to the meter system.

The recoverable section consisted of the release mechanism, six feet of 3/8 inch nylon line, the Savonius rotor current measuring system, nine feet of 3/8 inch nylon line, a 23 inch diameter, aluminum, buoyancy sphere, 600 feet of 3/16 inch polypropylene line (weighted with a ten-pound shot 200 feet below the surface), and a surface marker buoy. Swivels were inserted at each shackle connection to allow free rotation. A 1/4 inch plywood vane (2 feet by 3 feet) and a meter mounting frame were added to the Savonius meter system

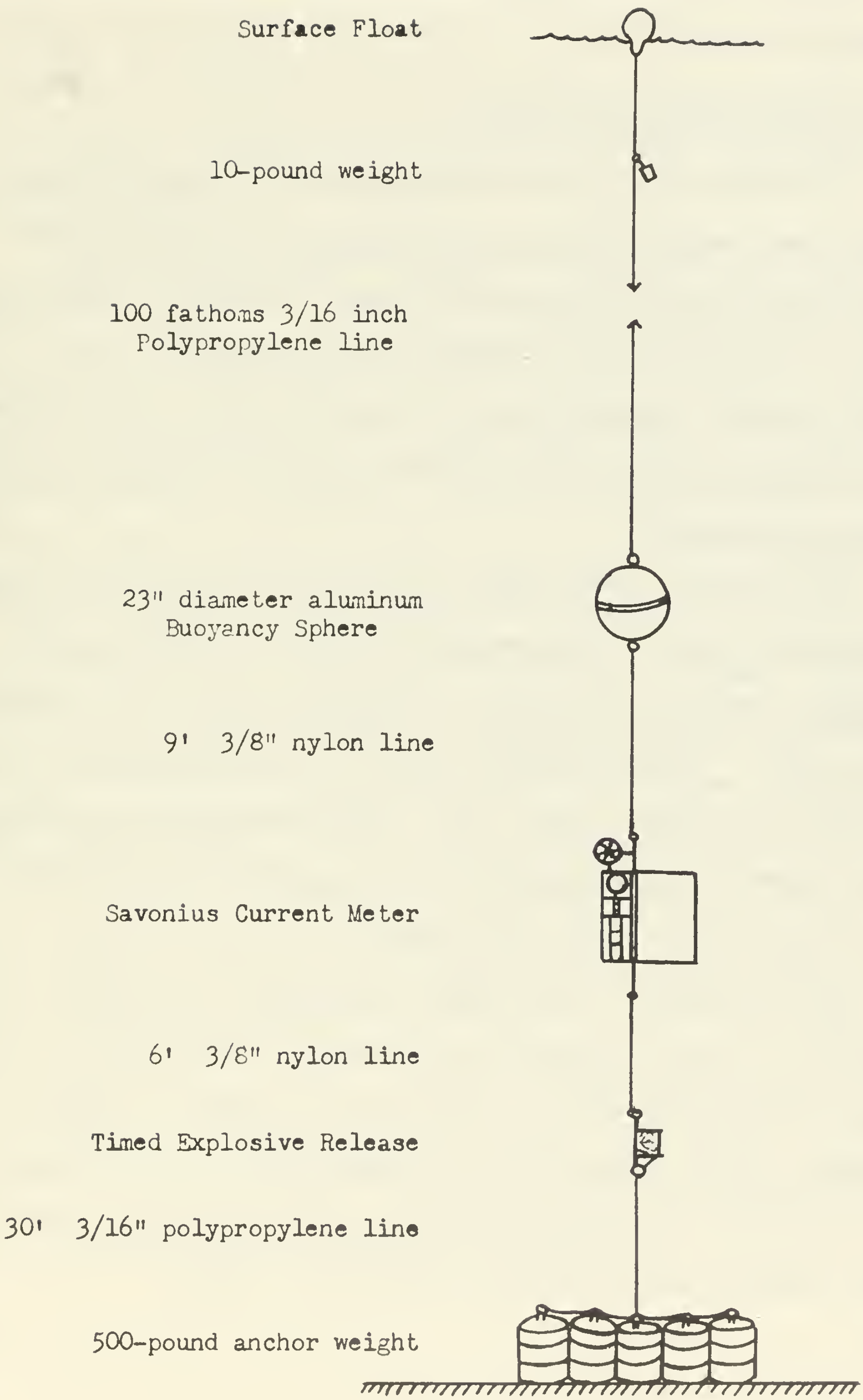


Fig. 4. The Taut Wire Mooring

to relieve the strain on the system and to provide rotational stability. The stabilizer vane was balanced by an 18-inch glass float attached opposite the vane.

B. THE CURRENT MEASURING SYSTEM

The sensor used in this investigation was a Model 501B, in situ current speed, direction, and temperature recording system, manufactured by Hydro Products, San Diego, California. Specifications given in this section are furnished by the manufacturer. The system includes a Savonius rotor, a direction vane, and an instrument package which includes a chart recorder, battery, thermistor, and readout electronics.

The underwater speed sensor is a precision balanced, high impact, polystyrene, Savonius rotor mounted on carbide to carbide, self-cleaning, bearings. It rotates at an angular rate of 83.5 revolutions at one knot. The useful range is 0.05 to 7.0 knots with an accuracy of ±3% of the reading (Franz, 1967). The rotation rate is determined from a magnetic pick-up whose output is a pulsed DC voltage which gives ten pulses per revolution of the rotor.

Current direction is measured with reference to magnetic north. The direction vane is magnetically coupled to the slider of a low torque potentiometer which is referenced by a magnetic compass. By applying a fixed voltage across the potentiometer, the voltage output on the slider is proportional to its degree of travel from magnetic north. Accuracy of the direction value is ±5 degrees.

The temperature sensor consists of a thermistor imbedded within the aluminum housing of the electronics sphere. It is accurate to within ±3 per cent of the value over a range of zero to 40 degrees Celsius. The thermistor stability is better than one per cent error in 24 hours. Its linearity is within ±2 per cent of straight line characteristics.

The electronics sphere contains the electronic circuitry, Rustrak two inch strip chart recorder, six volt nickel cadmium battery, and clock timer. Current speed read out circuitry consists of a pulse rate counter which generates a DC voltage proportional to the number of pulses received from the rotor. This DC level is recorded as current speed. Current direction readout is the amplified DC voltage from the compass slider. Water temperature is recorded on the strip chart as a measure of the DC level from the thermistor bridge. The three DC outputs are applied through a switching system to the recorder.

The Rustrak recorder provides a record of temperature, speed and direction with time. The recording cycle is 7.5 minutes during which period the speed and temperature are recorded for 1.5 minutes followed by a five-minute record of speed and direction. Each input is recorded on a four-second, time sharing basis. The recorder then turns off for the remainder of the cycle. The recorder may be set for a 30-day or a 7-day record. The timer starts a new cycle on an exact 7.5-minute interval each half hour for the 30-day record, and runs continuously on 7.5-minute intervals for the 7-day record.

The current meter weighs 38 pounds in sea water. Its frame is 102 cm. in length and 40 cm. in width. Table I is a summary of the manufacturer's measuring system specifications.

C. THE RELEASE MECHANISM

A timed release, the Braincon Model 422 release mechanism, manufactured by Braincon Corporation, Marion, Massachusetts, was used to permit the measuring system to return to the surface for recovery. After the timer counts down to the preset release time, an explosive squib is activated, which allows the release to disengage from the mooring line. The weight of the release in water is seventeen pounds.

D. MOORING PROCEDURE

Navigation was by radar and visual fixes on navigational aids in the Moss Landing area. Depths were determined using a Precision Depth Recorder.

The surface marker was towed behind the vessel while approaching the mooring site. At the mooring site the recoverable portion of the array was lowered into the water. When the vessel was positioned at the desired location,the anchor weight was launched. Table II contains the positions, depths, and dates of the moorings.

E. WIND RECORDING EQUIPMENT

Wind records were obtained from the California State Colleges Marine Laboratory at Moss Landing. They have a propellor and vane type anenometer coupled to a continuous strip chart recorder. The anemometer is located on the beach directly east of the site where the current arrays were positioned. The anemometer height is approximately

40 feet and it is completely unobstructed from the seaward side. Wind speed and direction were recorded continuously on a Weather Measure Corporation Wind Speed and Direction Chart #C101, by means of two inked styluses. The chart advanced at the rate of one inch per hour.

F. TIDE RECORDING EQUIPMENT

Tidal records were obtained from a standard recording tide gauge maintained by the Postgraduate School on Wharf No. 2 in the Monterey Harbor. The heights of the tide are the same at Moss Landing as at Monterey. The time difference is about three minutes and was neglected.

G. WAVE RECORDING EQUIPMENT

Wave data was obtained from a Mark IX Ocean Wave Recorder made by Mark Instruments, La Jolla, California. The recorder displays a continuous record received from a Snodgrass Mark IV pressure sensitive wave sensor located off Del Monte Beach. The system is maintained by the Postgraduate School.

TABLE I

CURRENT METER SPECIFICATIONS

SPEED SENSOR	
Angular Rate	83.5 Revolutions at one knot
Useful Range	0.05 - 7.00 knots
Accuracy	± 3% of the reading
Threshold Velocity	0.05 knot
DIRECTION	
Accuracy	± 5 degrees
TEMPERATURE	
Range	0.00 - 40 degrees Celsius
Accuracy	± 3% of the value
Thermistor Stability	Less than one per cent error in 24 hours
Linearity	Within ± 2% of straight line characteristics

TABLE II

MOORING SUMMARY

Mooring	Started/Ended (local time)	Record Length	Position	Depth (fathoms)	Remarks
I	101030 Sept 68 181000 Sept 68	89.25 hrs	36° 47.90'N 121° 48.90'W	90	1. No speed data obtained 2. Rustrak recorder malfunctioned 140345 Sept. 3. Wind data not available until 111600 Sept.
II	261230 Sept 68 031250 Oct. 68	168.3 hrs	36° 48.05'N 121° 48.70'W	82	1. Wind data not available until 270700 Sept. 2. Wind speed not available from 281400 to 300730 Sept.
III	171050 Oct. 68 240950 Oct. 68	168 hrs	36° 47.50'N 121° 49.35'W	110	

IV. DATA ANALYSIS

A. SAMPLING PROCEDURE AND DATA REDUCTION OF CURRENT RECORDS

The Rustrak recorder provided a record of temperature, current speed and direction with time. The recording cycle of the system is 7.5 minutes.

A sampling interval of 3.75 minutes (0.0625 hours) was used to convert the speed and direction records to digital form. The temperature was recorded every 7.5 minutes and the intermediate values were interpolated, which gave the equivalent of a 3.75 minute sampling interval. This interval allowed analysis of frequencies up to 0.133 cycles per minute, the "cut-off" or Nyquist frequency.

B. SAMPLING PROCEDURE AND DATA REDUCTION OF WIND RECORDS

The wind speed in miles per hour and the direction were recorded continuously at the rate of one inch per hour. The record was digitized at 1/16 of an inch giving a sampling interval of 3.75 minutes. Wind speed was converted to knots before performing a statistical analysis.

C. SAMPLING PROCEDURE AND DATA REDUCTION OF TIDAL RECORDS

The tide at Monterey is of the mixed type, in which the two high waters and the two low waters each day exhibit a diurnal inequality. The marigram for each observation period was digitized using a sampling interval of 3.75 minutes and the tidal level was referenced to Mean Lower Low Water (MLLW).

D. ELEMENTARY STATISTICS

All of the above data was transferred to IBM punch cards by personnel at the Postgraduate School Computer Facility.

"Current," a Fortran IV computer program, (see Appendix A) written by Dooley (1968), was modified to provide the following statistical and graphical outputs for each time series:

1. Hourly means
2. Daily means, medians, modes, and frequency distributions
3. Time series means, medians, modes, variances, standard deviations, and frequency distributions
4. Histograms.

These elementary statistics were computed using standard techniques with the exception of direction means which were computed by the method of Webster (1964). For analyzing wind records additional steps were inserted in the current program to change wind speed from miles per hour to knots and to alter the conventional wind direction by 180 degrees for easier comparison with direction of the current flow. Separate programs were written to provide a graphical display of each time series (i.e. temperature, wind speed and direction, and tidal fluctuations). The above programs were all run on the Postgraduate School IBM 360 computer. Summaries of the wind and current statistics are listed in Tables III-VI.

E. POWER SPECTRA ANALYSIS

Spectral analysis was applied to the individual time series to divide the variance of the time series into discrete bands. The power spectrum provides a measure of the density of the variance as a function of frequency. Power spectral computations were made on

the CDC 3600 computer at Fleet Numerical Weather Central, Monterey, using computer program GHOST, written at Scripps Institution of Oceanography, La Jolla, California. This program also provided coherence between selected time series. Frequencies between 0.133 cycles per minute and 0.375 cycles per day were analyzed. Normalized power spectra are plotted in Figures 22-27.

TABLE III

SUMMARY OF CURRENT STATISTICS

		WATER TEMPERATURE	CURRENT SPEED	CURRENT DIRECTION
Cruise I	MEAN	8.99 °C	N.A.	185 °T
	VARIANCE	0.13 $(°C)^2$	N.A.	6680 $(°T)^2$
	STANDARD DEVIATION	0.37 °C	N.A.	82 °T
	MEDIAN	9.12 °C	N.A.	195 °T
Cruise II	MEAN	11.87 °C	0.50 kts	139 °T
	VARIANCE	0.59 $(°C)^2$	0.09 $(kts)^2$	6200 $(°T)^2$
	STANDARD DEVIATION	0.77 °C	0.29 kts	79 °T
	MEDIAN	11.33 °C	0.42 kts	190 °T
Cruise III	MEAN	11.35 °C	0.67 kts	196 °T
	VARIANCE	0.36 $(°C)^2$	0.08 $(kts)^2$	7099 $(°T)^2$
	STANDARD DEVIATION	0.60 °C	0.28 kts	84 °T
	MEDIAN	11.25 °C	0.72 kts	196 °T

TABLE IVa

DAILY SUMMARY OF CURRENT DATA

CRUISE I (1030 10 Sept. - 0345 14 Sept.)

	WATER TEMPERATURE (°C)		CURRENT SPEED(knots)		CURRENT DIRECTION (°T)	
	Mean	Mode(%)	Mean	Mode(%)	Mean	Mode(%)
10 Sept.	9.02	9.00 - 9.25(36.6)	N.A.	N.A.	158	090 - 100(21.4) 190 - 200(20.1)
11 Sept.	8.98	9.00 - 9.25(42.7)	N.A.	N.A.	197	240 - 250(20.8) 090 - 100(15.6)
12 Sept.	9.01	9.00 - 9.25(66.9)	N.A.	N.A.	184	240 - 250(22.1) 090 - 100(16.1)
13 Sept.	8.97	9.00 - 9.25(42.7)	N.A.	N.A.	178	240 - 250(10.4) 090 - 100(9.9)
TOTAL RECORD	8.99	9.00 - 9.25(49.3)	N.A.	N.A.	185	240 - 250(18.4) 090 - 100(14.5)

TABLE IVb

DAILY SUMMARY OF CURRENT DATA

CRUISE II (1230 26 Sept. - 1250 3 Oct.)

	WATER TEMPERATURE (°C)		CURRENT SPEED(knots)		CURRENT DIRECTION(°T)	
	Mean	Mode(%)	Mean	Mode(%)	Mean	Mode(s) (%)
26 Sept.	12.00	12.00-12.25(21.9) 12.50-12.75(21.4)	0.41	0.15-0.20(19.3)	147	210-220(15.6) 100-110(12.0)
27 Sept.	11.74	12.00-12.25(22.7) 11.50-11.75(20.4)	0.42	0.20-0.25(12.2)	137	210-220(14.6) 100-110(13.5)
28 Sept.	11.88	12.00-12.25(37.8)	0.48	0.35-0.40(11.5)	141	100-110(19.5) 210-220(18.0)
29 Sept.	11.96	12.00-12.25(24.7) 11.00-11.25(18.2)	0.45	0.20-0.25(12.8)	150	200-210(24.0) 100-110(12.2)
30 Sept.	12.01	11.00-11.25(30.7) 12.75-13.00(21.6)	0.46	0.95-1.00(13.3) 0.25-0.30(11.2) 0.15-0.20(10.4)	141	210-220(15.9) 100-110(9.4)
1 Oct.	11.93	11.00-11.25(32.0) 13.00-13.25(13.0)	0.54	0.95-1.00(16.4) 0.15-0.20(12.0)	136	210-220(18.8) 100-110(9.1)
2 Oct.	11.72	11.00-11.25(26.0)	0.61	0.95-1.00(26.0) 0.15-0.20(11.2)	128	210-220(15.9) 060-070(12.2) 100-110(10.4)
TOTAL RECORD	11.87	11.00-11.25(23.3) 12.00-12.25(16.7)	0.50	0.95-1.00(13.7) 0.15-0.20(10.5)	139	210-220(15.5) 100-110(11.9)

TABLE IVc

DAILY SUMMARY OF CURRENT DATA

CRUISE III (1050 17 Oct. - 0950 24 Oct.)

	WATER TEMPERATURE (°C)		CURRENT SPEED(knots)		CURRENT DIRECTION(°T)	
	Mean	Mode(%)	Mean	Mode(%)	Mean	Mode(s)(%)
17 Oct.	11.20	10.50-10.75(18.3)	0.49	0.25-0.30(11.2)	174	200-210(17.9) 020-030(17.0)
18 Oct.	11.14	11.50-11.75(25.3) 11.00-11.25(24.0)	0.53	0.30-0.35(12.0)	147	200-210(20.6) 020-030(13.3)
19 Oct.	11.26	11.75-12.00(18.0)	0.65	0.95-1.00(20.8) 0.35-0.40(10.7)	182	200-210(27.1) 020-030(16.9)
20 Oct.	11.38	11.75-12.00(20.3)	0.72	0.95-1.00(35.4)	200	200-210(37.2) 020-030(13.8)
21 Oct.	11.48	10.75-11.00(25.0) 12.00-12.25(24.5)	0.74	0.95-1.00(29.4)	200	200-210(41.4) 020-030(17.2)
22 Oct.	11.54	12.00-12.25(28.1) 10.75-11.00(21.4)	0.73	0.95-1.00(31.5)	208	200-210(43.8) 020-030(10.7)
23 Oct.	11.53	12.00-12.25(34.2) 10.75-11.00(17.8)	0.70	0.95-1.00(34.1)	200	200-210(34.2) 020-030(11.2)
TOTAL RECORD	11.35	12.00-12.25(16.8) 11.00-11.25(15.7)	0.67	0.95-1.00(26.1)	196	200-210(34.2) 020-030(14.3)

TABLE V

SUMMARY OF WIND STATISTICS

		WIND SPEED	WIND DIRECTION*
Cruise I	MEAN	7.05 kts	079 °T
	VARIANCE	16.01 $(kts)^2$	9377 $(°T)^2$
	STANDARD DEVIATION	4.00 kts	97 °T
	MEDIAN	6.75 kts	137 °T
Cruise II	MEAN	9.43 kts	058 °T
	VARIANCE	5.33 $(kts)^2$	11,031 $(°T)^2$
	STANDARD DEVIATION	2.31 kts	105 °T
	MEDIAN	9.25 kts	080 °T
Cruise III	MEAN	11.48 kts	327 °T
	VARIANCE	4.15$(kts)^2$	13,514 $(°T)^2$
	STANDARD DEVIATION	2.04 kts	116 °T
	MEDIAN	10.70 kts	275 °T

*Wind direction is direction toward which the wind is blowing

TABLE VIa

DAILY SUMMARY OF WIND DATA

CRUISE I (1600 11 Sept. - 0400 14 Sept.)

	WIND SPEED(knots)		WIND DIRECTION(°T)*	
	Mean	Mode(%)	Mean	Mode(%)
11 Sept.	6.37	2.5- 3.0(9.4) 8.5- 9.0(8.6) 11.0-11.5(8.6)	049	240-250(17.3) 260-270(15.0) 080-090(13.4)
12 Sept.	7.50	7.5- 8.0(7.3) 13.0-13.5(6.8) 3.0- 3.5(6.0)	031	070-080(9.1) 290-300(7.3)
13 Sept.	7.35	5.0- 5.5(9.1) 3.0- 3.5(8.9)	120	090-100(18.2) 130-140(10.9) 260-270(8.6)
TOTAL RECORD	7.05	3.0- 3.5(9.6)	079	260-270(13.2) 090-100(8.6)

*Wind Direction is direction toward which the wind is blowing

TABLE VIb

DAILY SUMMARY OF WIND DATA

CRUISE II (0700 27 Sept. - 1400 3 Oct.)

	WIND SPEED(knots)		WIND DIRECTION (°T)*	
	Mean	Mode(%)	Mean	Mode(%)
27 Sept.	8.83#	6.5- 7.0(16.2)	071	080-090(40.4)
28 Sept.	7.49#	6.5- 7.0(20.3)	023	070-080(26.6)
29 Sept.	N.A.#	N.A.	053	080-090(31.8)
30 Sept.	9.92#	9.5-10.0(15.1)	121	090-100(35.4) 250-260(27.1)
1 Oct.	10.64	8.5- 9.0(10.8)	094	250-260(35.7) 090-100(26.3)
2 Oct.	9.30	9.5-10.0(26.3)	040	070-080(15.4)
TOTAL RECORD	9.43	9.5-10.0(14.5)	058	080-090(16.6) 250-260(10.8)

*Wind direction is direction toward which the wind is blowing

#Wind speed not available from 1400 28 Sept. to 0730 30 Sept. These statistics based on less than a 24 hour sample

TABLE VIc

DAILY SUMMARY OF WIND DATA

CRUISE III (1500 16 Oct. - 1000 24 Oct.)

	WIND SPEED(knots)		WIND DIRECTION(°T)*	
	Mean	Mode(%)	Mean	Mode(%)
16 Oct.	10.53	10.0-10.5(37.5)	338	270-280(35.4) 070-080(16.7)
17 Oct.	11.77	10.0-10.5(26.9)	336	270-280(34.6) 070-080(26.0)
18 Oct.	10.88	9.5-10.0(21.9)	312	270-280(49.7) 070-080(21.1)
19 Oct.	11.86	9.5-10.0(18.0) 13.0-13.5(13.9)	004	070-080(31.0) 270-280(28.9)
20 Oct.	12.45	13.0-13.5(18.4) 12.0-12.5(16.4) 9.5-10.0(12.9)	304	270-280(39.1) 070-080(19.5)
21 Oct.	11.53	9.5-10.0(30.5)	335	270-280(42.2) 070-080(23.7)
22 Oct.	10.61	10.0-10.5(30.5)	347	270-280(28.9) 070-080(10.2)
23 Oct.	11.16	9.5-10.0(18.7)	322	270-280(38.0) 070-080(9.9)
TOTAL RECORD	11.47	9.5-10.0(20.2)	327	270-280(39.4) 070-080(19.0)

*Wind direction is direction toward which the wind is blowing

V. OBSERVATIONAL RESULTS

A. GENERAL DESCRIPTION OF THE NEAR-BOTTOM CURRENTS

Three observations were made along the canyon axis approximately 40 feet off of the bottom at depths varying from 80 fathoms to 110 fathoms. A summary of all statistical computations is found in Tables IV through VI. Histograms and time series plots are displayed in figures 5 through 21.

All records reveal a periodic nature in direction, speed, and temperature. The modal directions are generally along the canyon axis at each location. The speed varies from 0.08 knot to in excess of one knot. Both records II and III exhibit a mode at 0.95 knot to 1.00 knot. In reality these values for cruises II and III (13% and 26% respectively) are for currents 0.95 knot and greater. Other than these peaks in the histograms, there are modes at 0.15 knot and 0.35 knot, and both records are skewed toward the higher speeds.

In general the directions conform to the topography of the canyon which agrees with all previous investigations. The speeds recorded are considerably higher than those previously measured in this canyon and others.

B. OBSERVATIONS OF CURRENT DIRECTION

A visual inspection of the time series plots reveals several striking features and correlations. Initially, it is evident that there is a definite periodic reversal of current direction which is generally along the canyon axis. At 110 fathoms (cruise III) the axis trends 025-205°T and the primary current directions are 020-200°T.

At this depth the canyon is V-shaped, steep-sided, and well-defined. At 90 fathoms (cruise I) the down-canyon flow is 245^{o} and the canyon axis trends 240^{o}T. In an up-canyon (landward) direction the predominant current is 095^{o} while the canyon axis is about 060^{o} but is altering its course to the eastward. The canyon floor widens and the axis is less well defined above this depth. At 80 fathoms (cruise II) the canyon divides into two branches (065^{o} and 085^{o}) landward but runs as a single channel 235^{o}T down-canyon. The current flow in this region was mainly 215^{o} down-canyon. Up-canyon flow was primarily 105^{o} with a secondary mode of 065^{o}. Variations in current direction from the confines of the charted canyon axis can be attributed to local topographic features which are not evident on the charts of the area. Several irregularities in the topography were noted in this region using the vessels' Precision Depth Recorder (PDR), however it was beyond the scope of this research to exactly position these anomolies.

Close inspection of the time series plots disclosed many prominant correlations between series. The direction changes occur generally at high and low tides and correspond to periods of minimum speed. On rising tide, the current flow is down-canyon while on falling tide the flow is up-canyon.

C. OBSERVATIONS OF CURRENT SPEED

The up-canyon flow, associated with the falling tide, is a cold current which increases in speed rapidly from near zero to approximately one knot (figure 8). This speed is sustained for two to three hours and then decreases slowly to a minimum. On the rising tide, the

current warms with time increasing slowly to a maximum speed which varies proportionally with the tidal range (figure 10). The current then decreases slowly again to another minimum value, after which the cycle is repeated.

When the two high tides and the two low tides are of equal magnitude, the above relationship is very well defined. This is most evident on the records from cruise III (17-24 October, 1968). When there is a large variation between the two high tides and the two low tides, the relationship between the currents and the tidal phase becomes vague. However, as the tidal fluctuations even out, the relationship with the current again becomes clear. This can be seen on the records from cruise II (26 Sept - 3 Oct.).

The average values for current speed are 0.50 knot and 0.67 knot with standard deviations of 0.29 knot and 0.28 knot respectively. The variances are 0.09 and 0.08 $(\text{knot})^2$.

D. OBSERVATIONS OF WATER TEMPERATURE

On cruise I the temperature variation was over a narrow range of 8.0°C to 9.5°C. Subsequent records display a wider range of warmer temperatures associated with the Davidson Current which is flowing during this period (Skogsberg, 1936). The range at 80 fathoms was 10.6°C to 13.8°C. At 110 fathoms, the range narrowed to 10.0°C to 12.4°C. The average temperatures for the three periods were 8.0°C, 11.87°C, and 11.35°C.

E. WIND OBSERVATIONS

The winds exhibited a characteristic on-shore/off-shore diurnal variation. Average speeds were on the order of ten knots, reaching their maximum speed in the early afternoon and their minimum shortly after midnight.

The wind conditions did not appear to exhibit an appreciable influence on the near-bottom currents in either magnitude or direction.

F. WAVE DATA

During the first cruise, wave conditions ranged from calm seas to wave amplitudes of about 0.4 foot with periods of 8 seconds to 12 seconds.

During the last two cruises, the wave conditions increased from a period of 10 seconds to 12 seconds and amplitudes of 0.2 foot to periods of 20 seconds with approximately one foot amplitudes and then began subsiding again.

In general, it appears as if the longer period, higher amplitude waves had the effect of increasing the magnitude of the current speed and prolonging the lengths of the high speed bursts in both up-canyon and down-canyon directions; however, time was not available to analyze this relationship in detail.

G. SPECTRAL ANALYSIS

The normalized energy density curves (figures 25-30) exhibit consistent peaks in the power spectrum for each parameter around the following periods:

Tidal: 24, 12.5, 8, 6, 5, 2.75 hours
Current Direction: 12.5, 6, 3.5, 3, 2.5 hours
Current Speed: 12.5, 6, 4, 2.5 hours
Water Temperature: 12.5, 6, 4 hours
Wind Direction: 24, 8 hours
Wind Speed: 24, 12, 8 hours

There is good correlation between the 12.5, 6, and 5 hour periods of the tide and current direction for all three records.

The current direction shows very good correlation with both the temperature and current speed for nearly all periods.

With the exception of the semi-diurnal component, there appears to be no correlation between:

Current Speed	- Wind Speed Wind Direction
Current Direction	- Wind Speed Wind Direction
Tide	- Wind Speed

Although it is not consistent, there does appear to be some correlation between the tide and the wind direction.

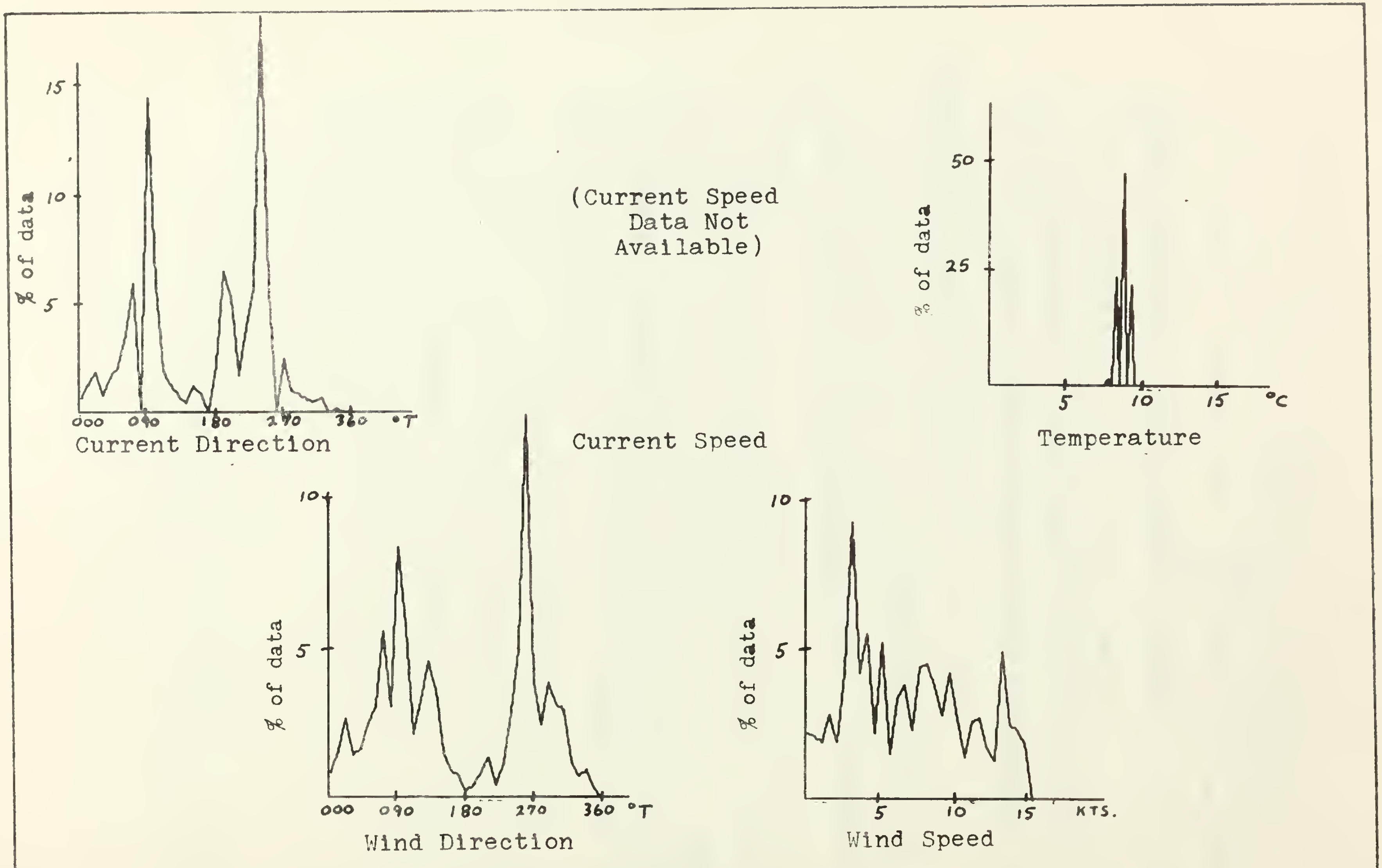


Fig.5. Histograms - Cruise I

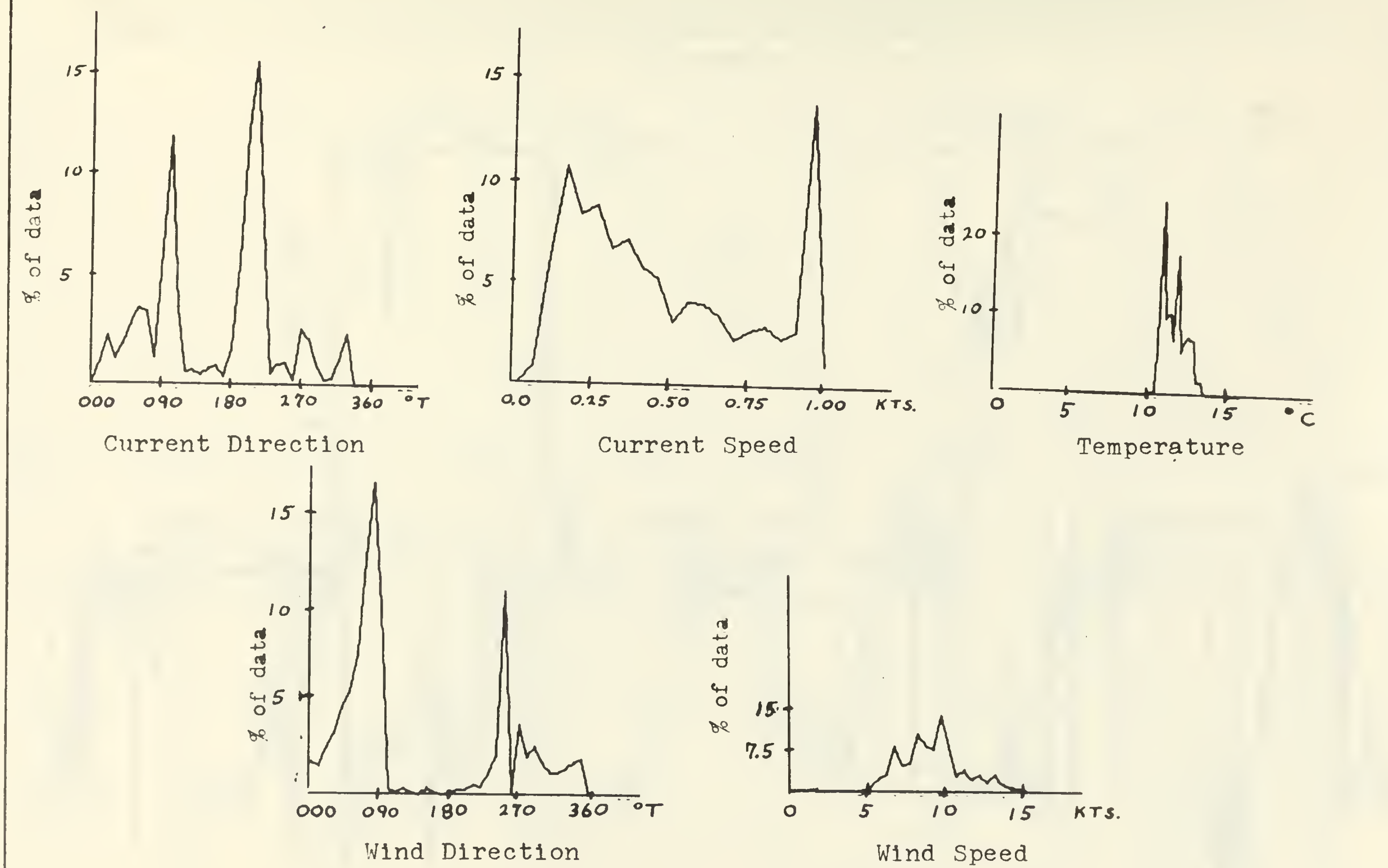


Fig.6. Histograms - Cruise II

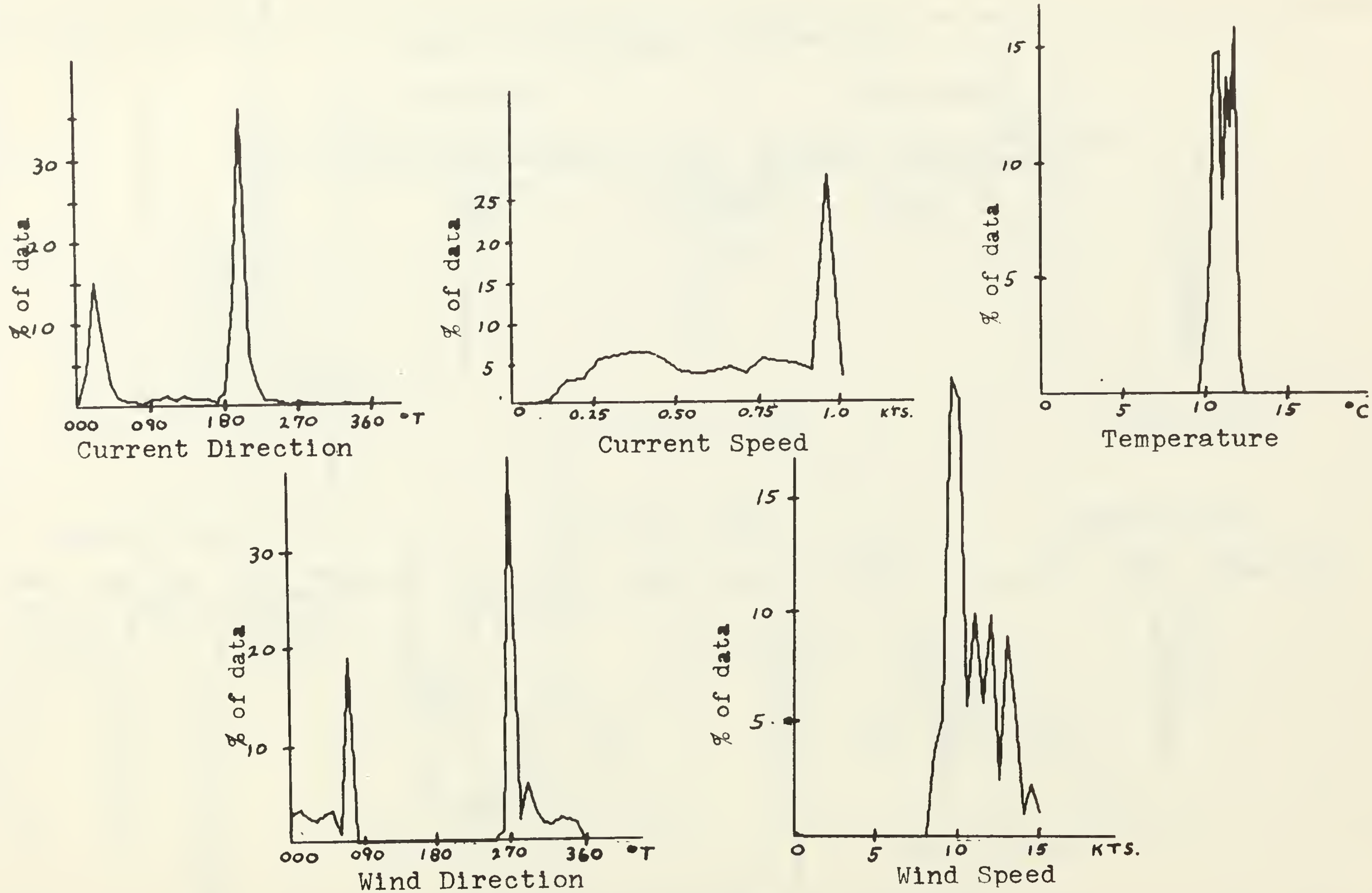
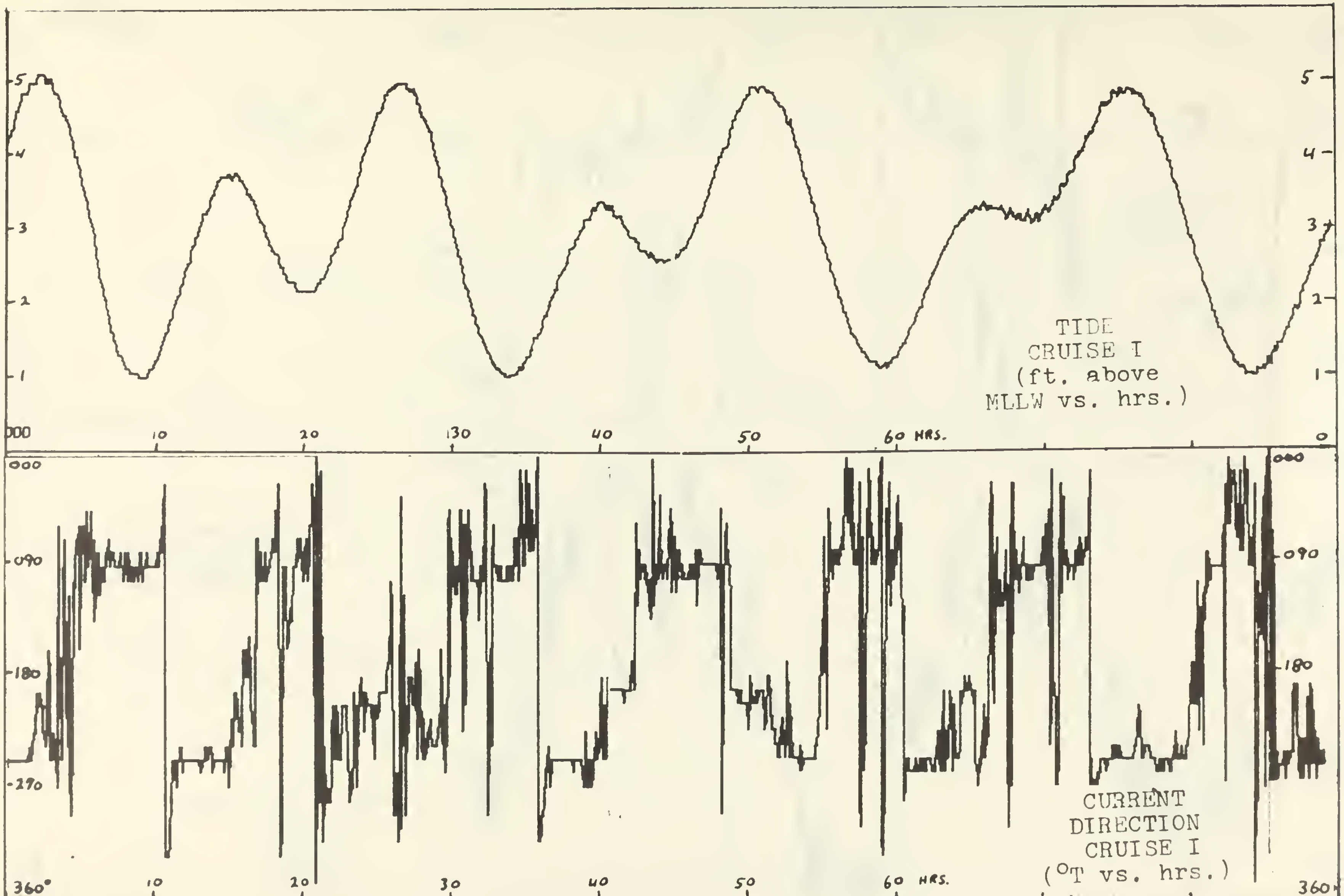


Fig.7. Histograms - Cruise III


TIDE
CRUISE I
(ft. above
MLLW vs. hrs.)
CURRENT
DIRECTION
CRUISE I
(°T vs. hrs.)
000
10
20
30
40
50
60 HRS.
0
5
4
3
2
1
090
180
270
360°
360
Figure 8.

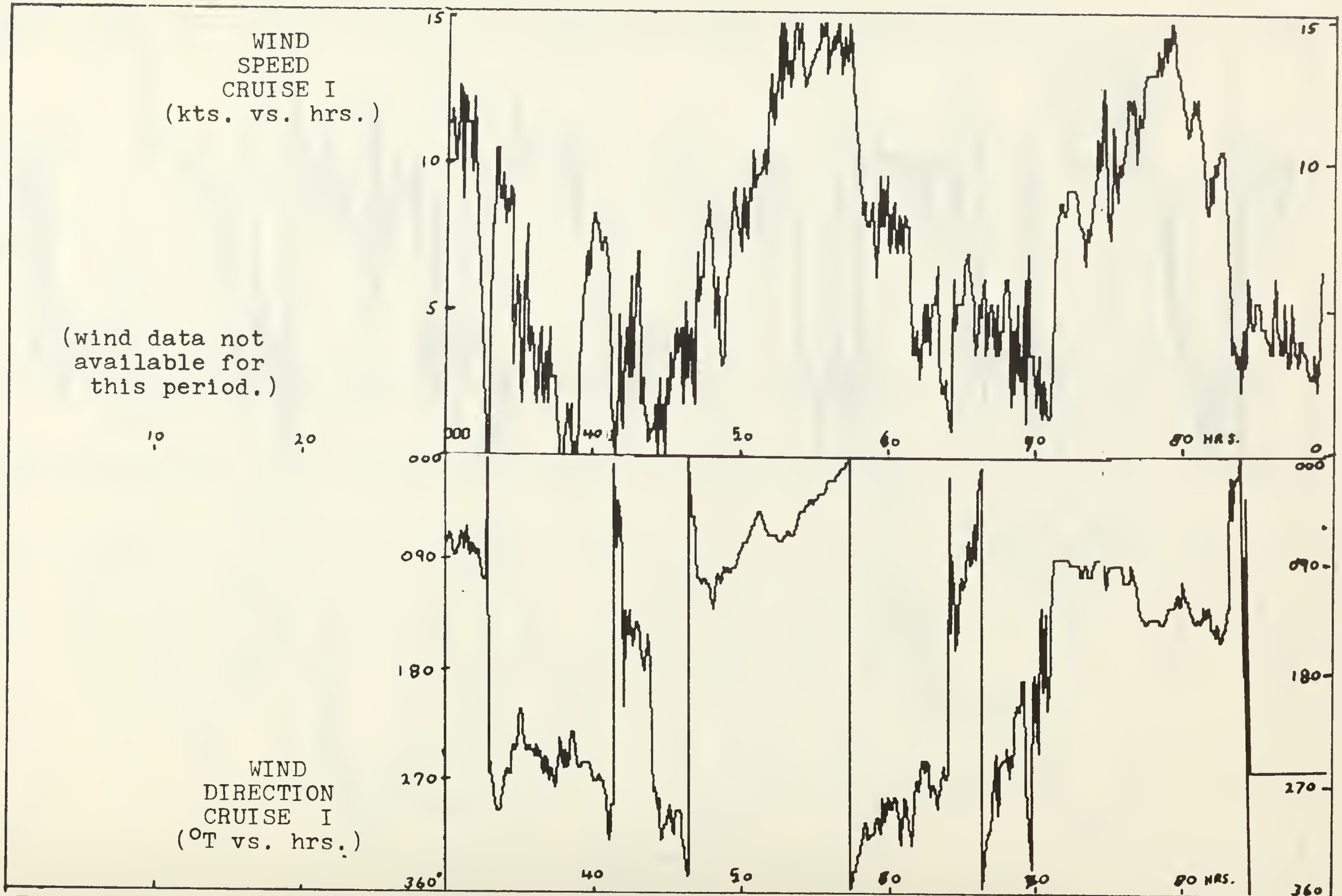

WIND
SPEED
CRUISE I
(kts. vs. hrs.)
(wind data not
available for
this period.)
WIND
DIRECTION
CRUISE I
(°T vs. hrs.)
15
10
5
000
090
180
270
360°
10
20
40
50
60
70
80 HRS.

Figure 9.

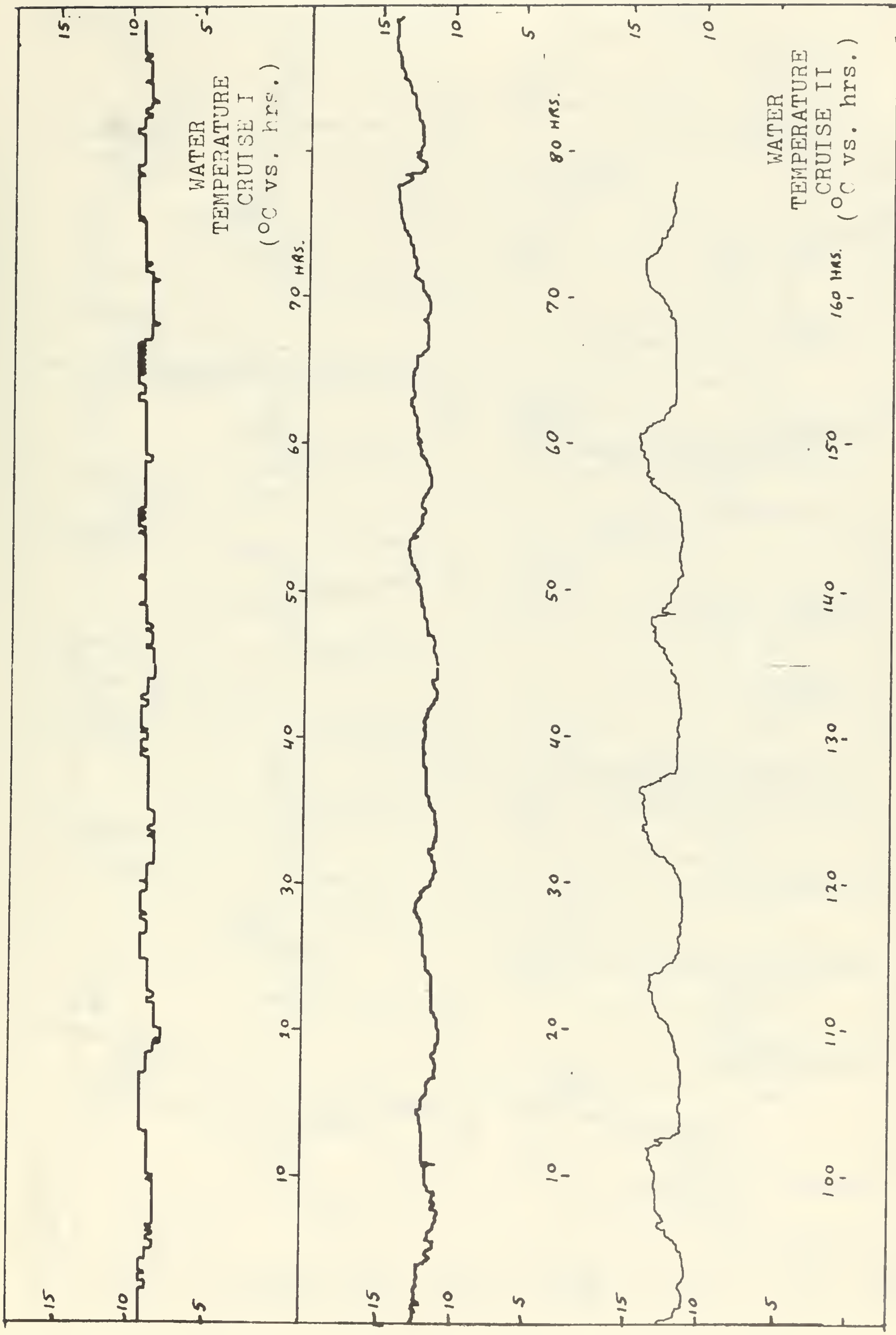

WATER
TEMPERATURE
CRUISE I
(°C vs. hrs.)
WATER
TEMPERATURE
CRUISE II
(°C vs. hrs.)
70 HRS.
80 HRS.
160 HRS.

Figure 10.

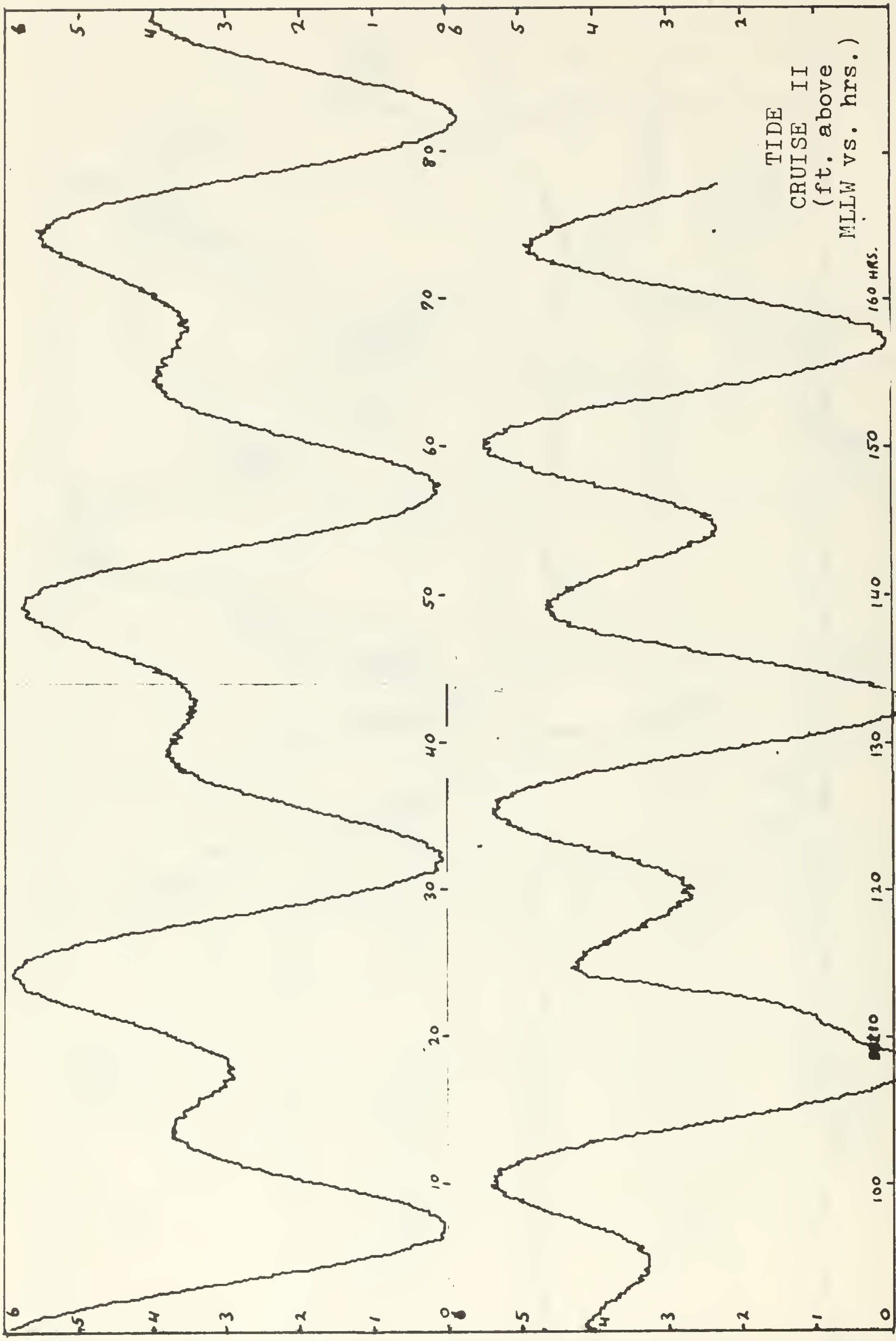


Figure 11.

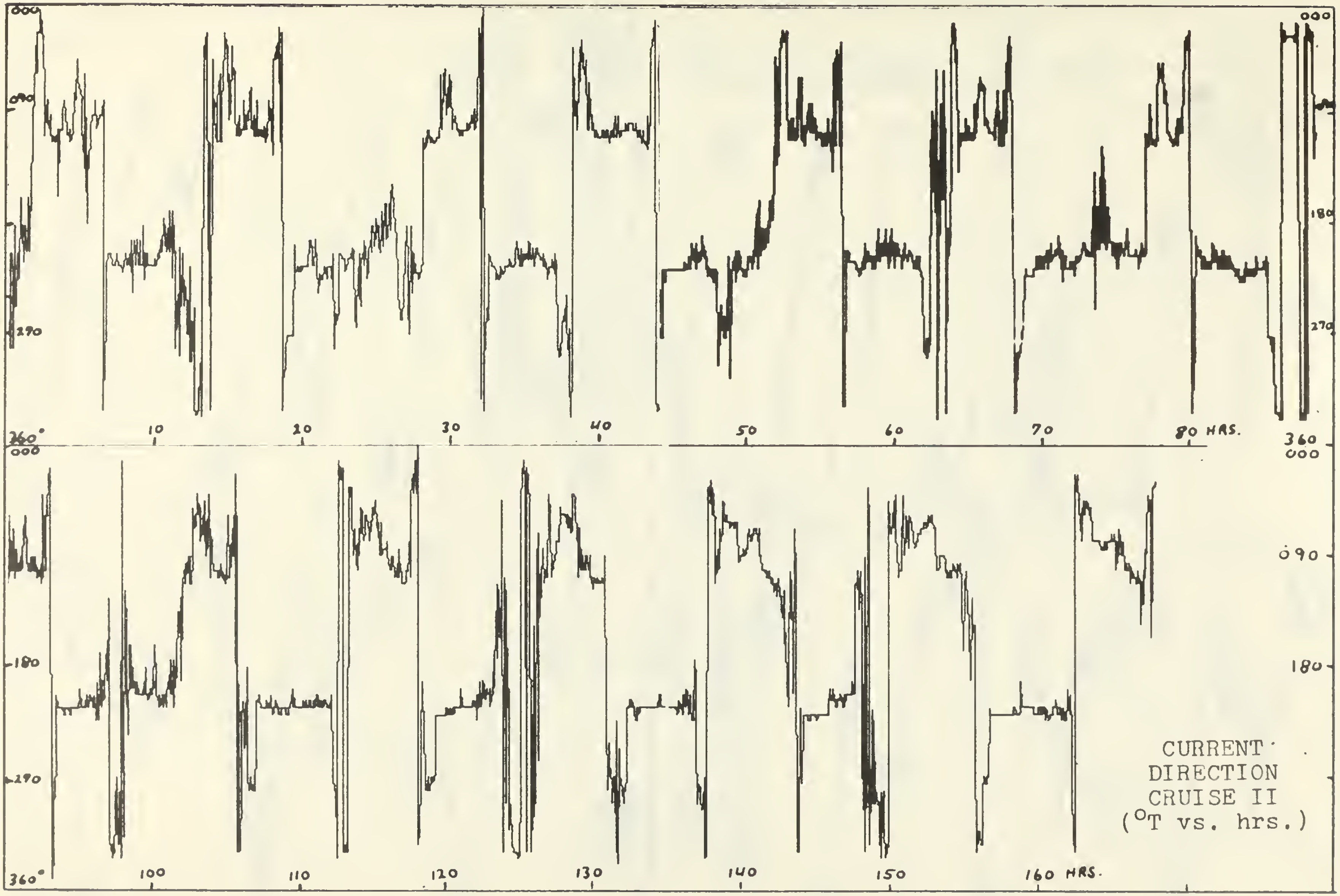

000
090
180
270
360°
10
20
30
40
50
60
70
80 HRS.
360
000
090
180
270
360°
100
110
120
130
140
150
160 HRS.
CURRENT
DIRECTION
CRUISE II
(°T vs. hrs.)

Figure 12.

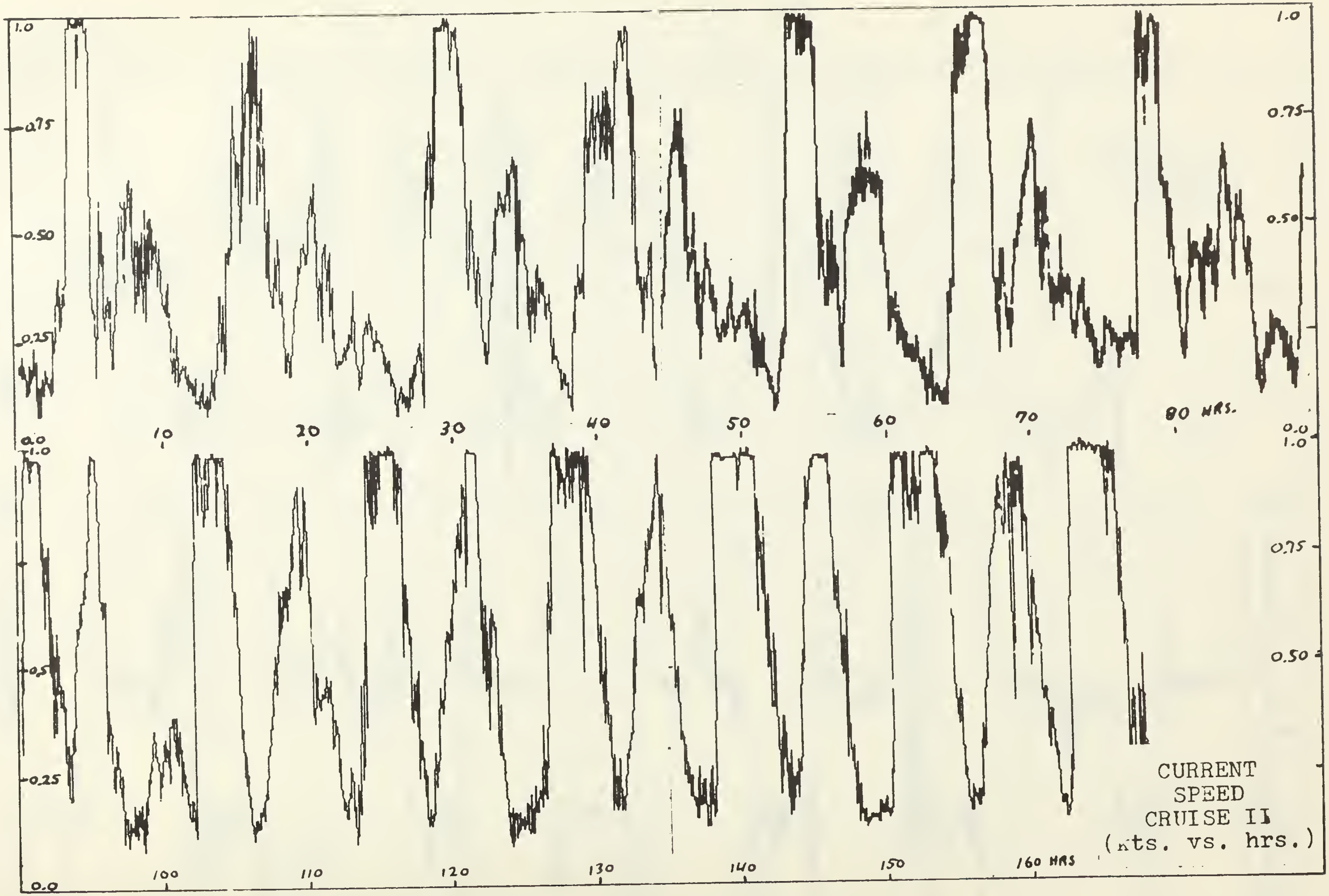
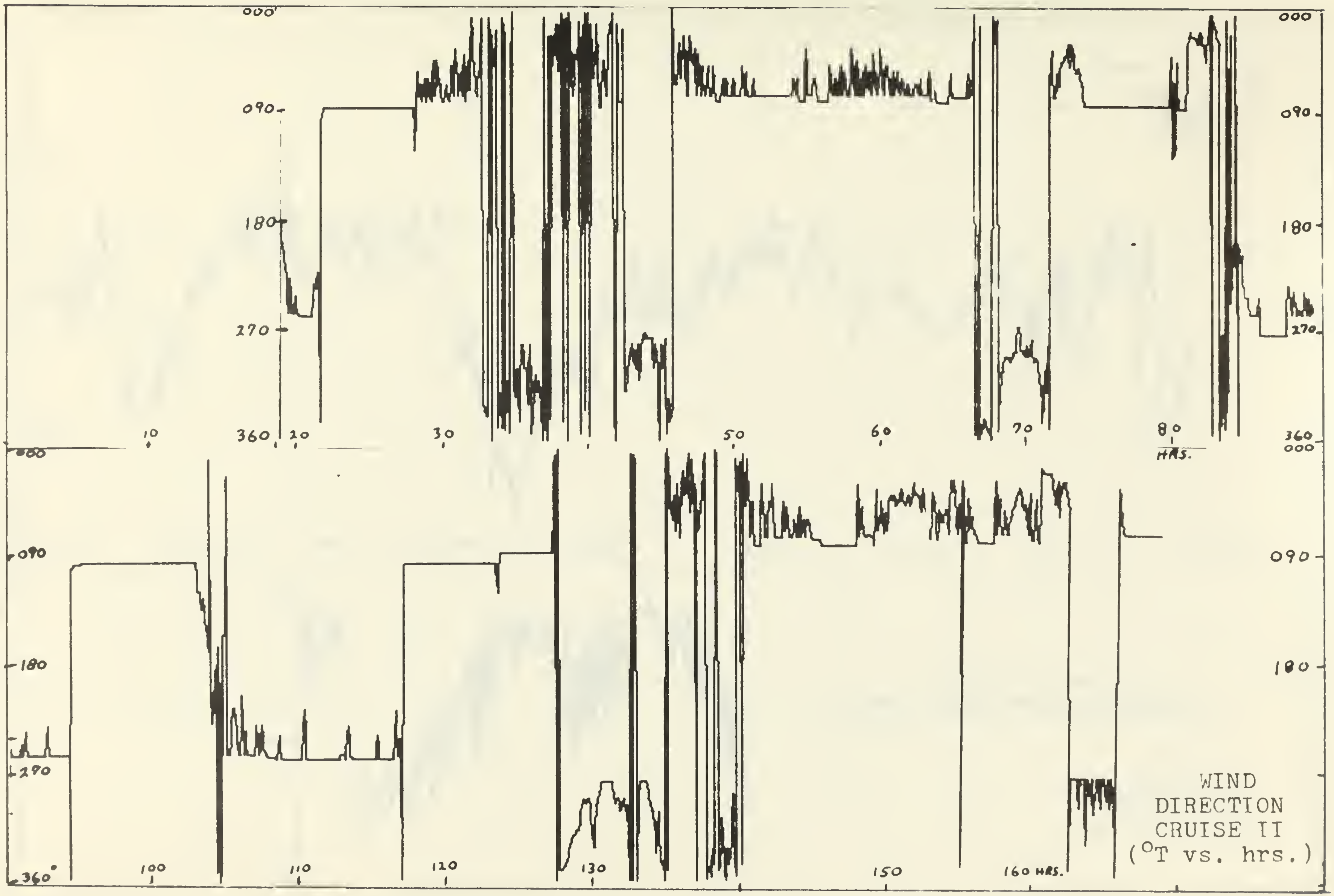


Figure 13.



WIND
DIRECTION
CRUISE II
(^{o}T vs. hrs.)

Figure 14.

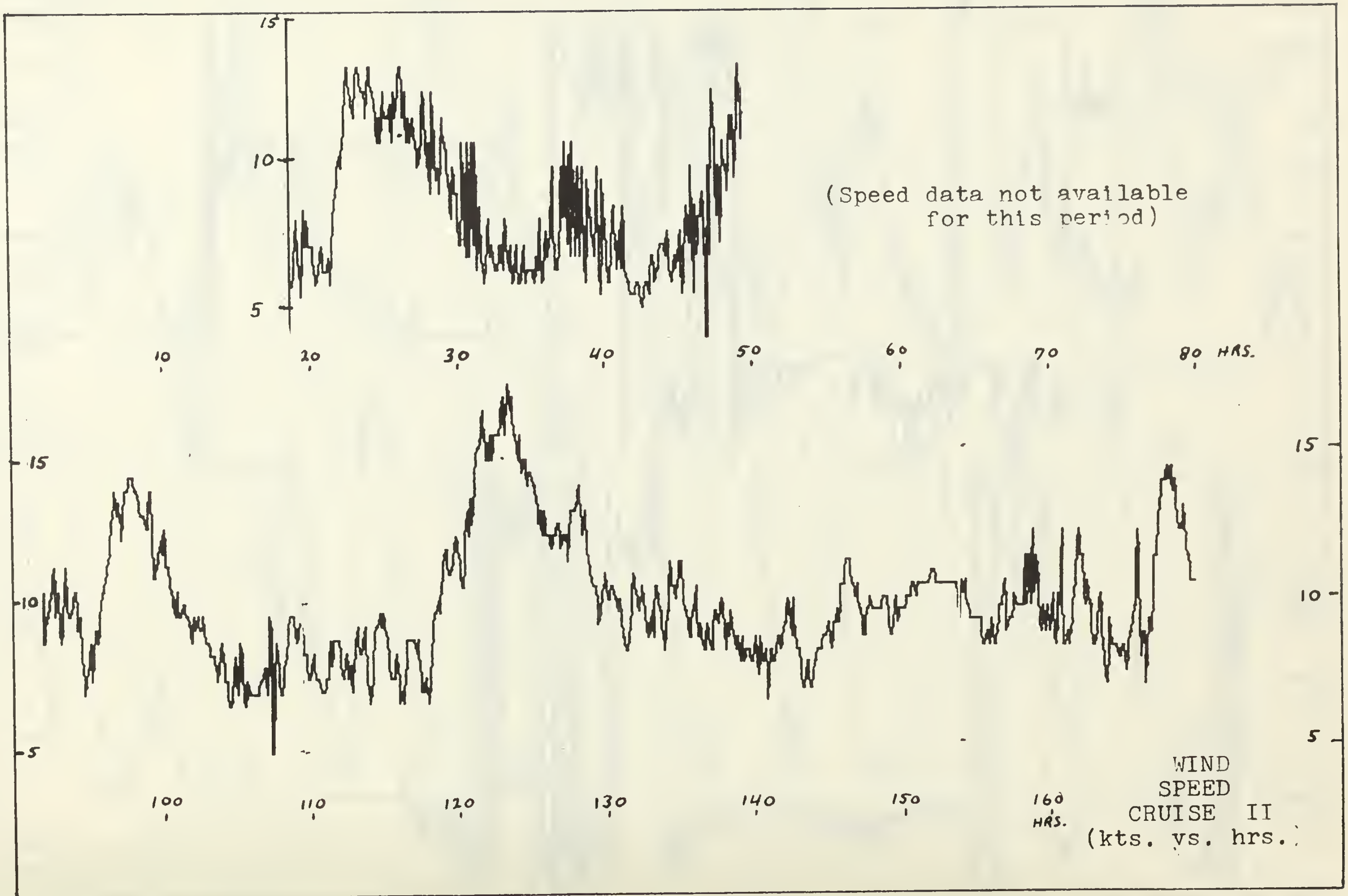

15
10
5
10
20
30
40
50
60
70
80 HRS.
(Speed data not available
for this period)
15
10
5
100
110
120
130
140
150
160
HRS.
WIND
SPEED
CRUISE II
(kts. vs. hrs.)

Figure 15.

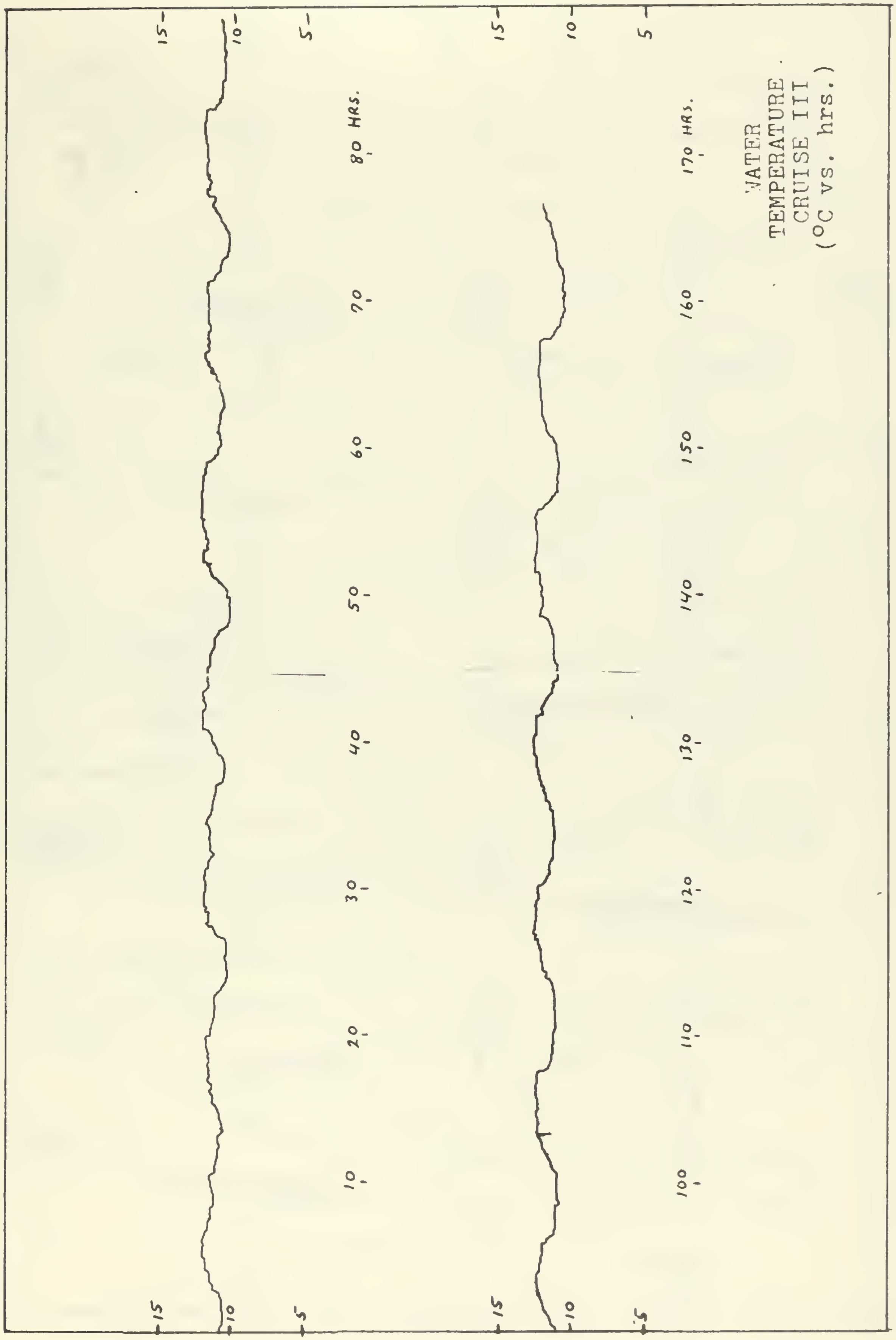

WATER
TEMPERATURE
CRUISE III
(°C vs. hrs.)
15
10
5
10
20
30
40
50
60
70
80 HRS.
100
110
120
130
140
150
160
170 HRS.

Figure 16.

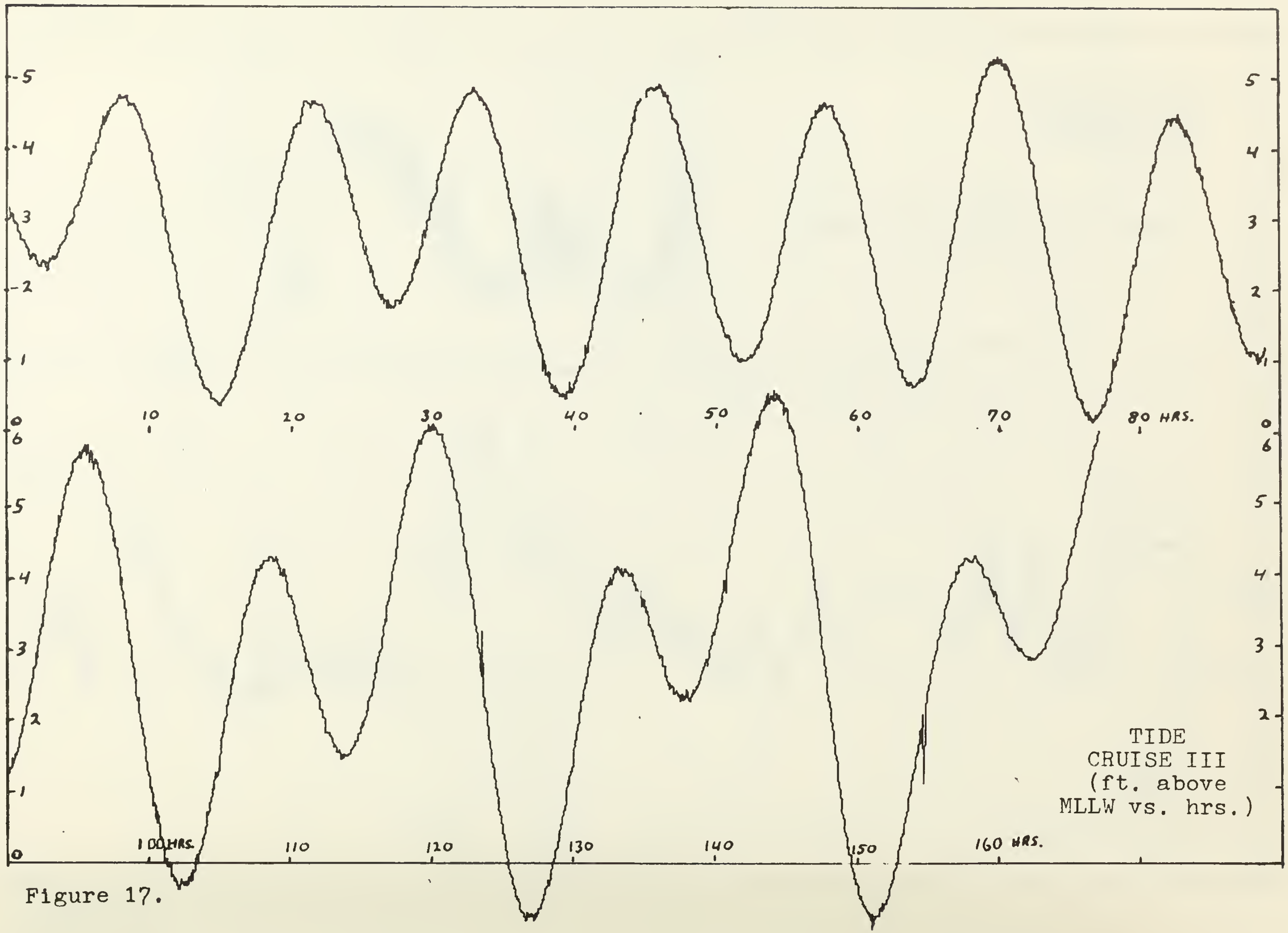

TIDE
CRUISE III
(ft. above
MLLW vs. hrs.)
10
20
30
40
50
60
70
80 HRS.
100 HRS.
110
120
130
140
150
160 HRS.
0
1
2
3
4
5
6

Figure 17.

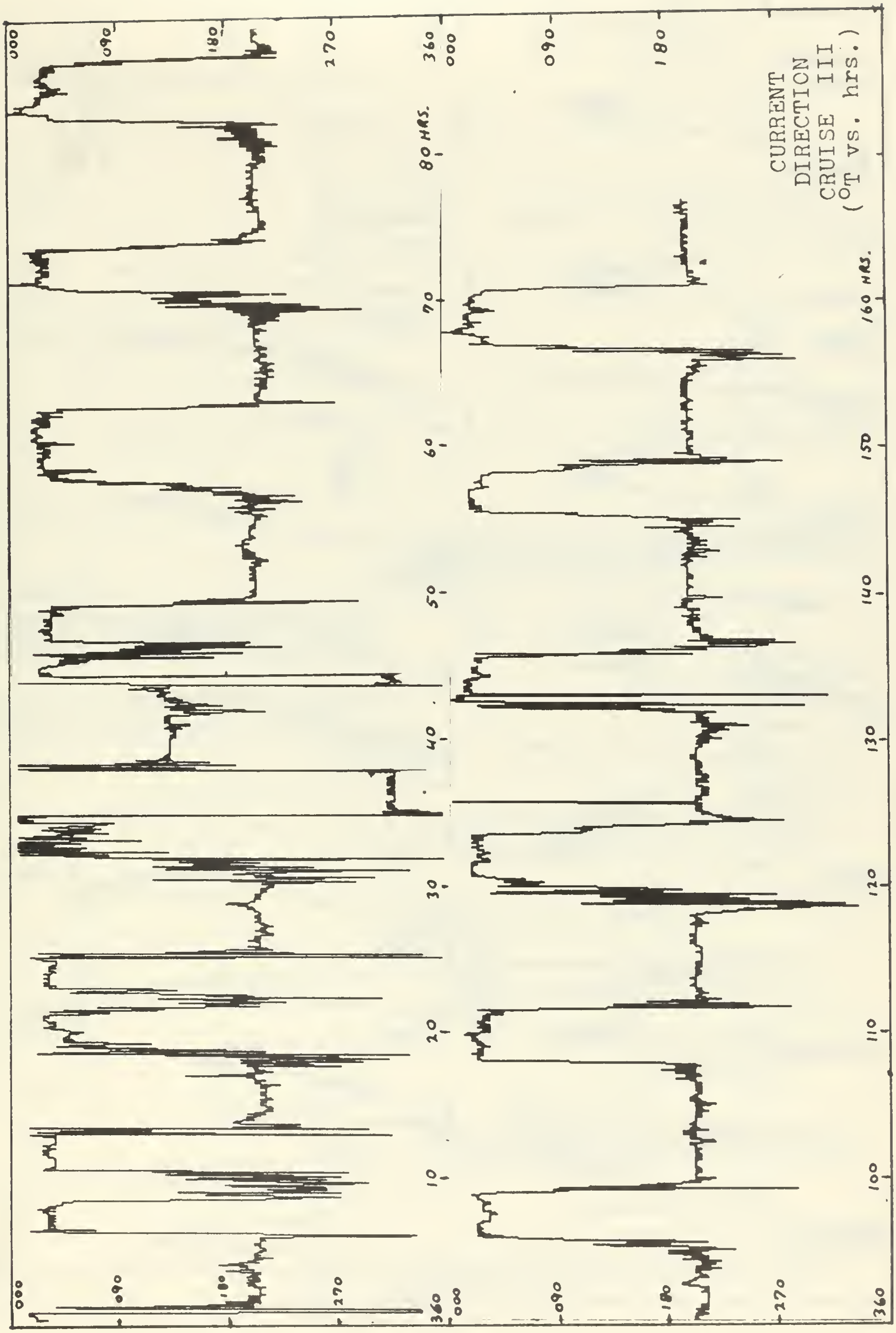

CURRENT
DIRECTION
CRUISE III
(°T vs. hrs.)
000
090
180
270
360
10
20
30
40
50
60
70
80 HRS.
100
110
120
130
140
150
160 HRS.

Figure 18.

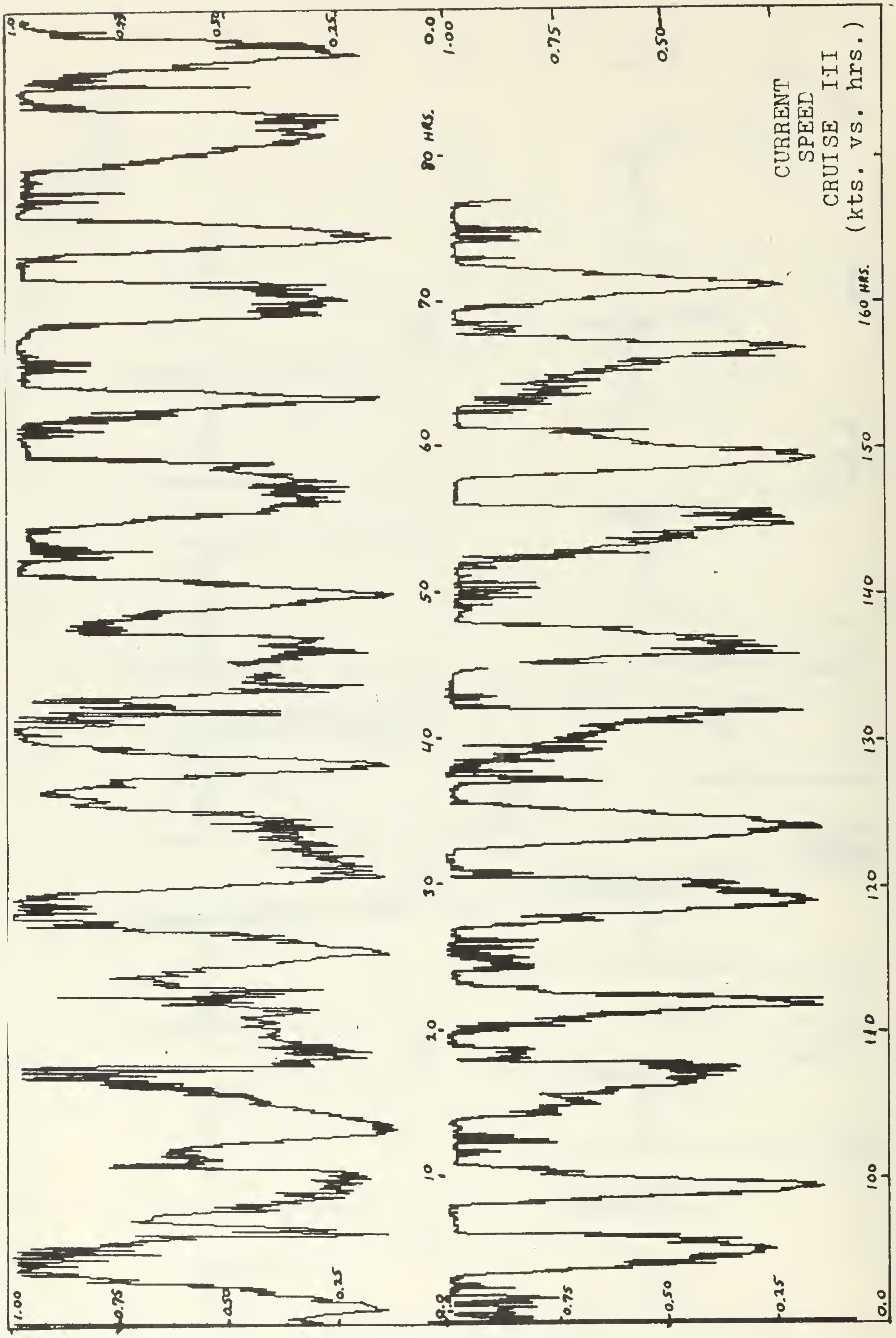

CURRENT
SPEED
CRUISE III
(kts. vs. hrs.)
1.00
0.75
0.50
0.25
0.0
10
20
30
40
50
60
70
80 HRS.
100
110
120
130
140
150
160 HRS.

Figure 19.

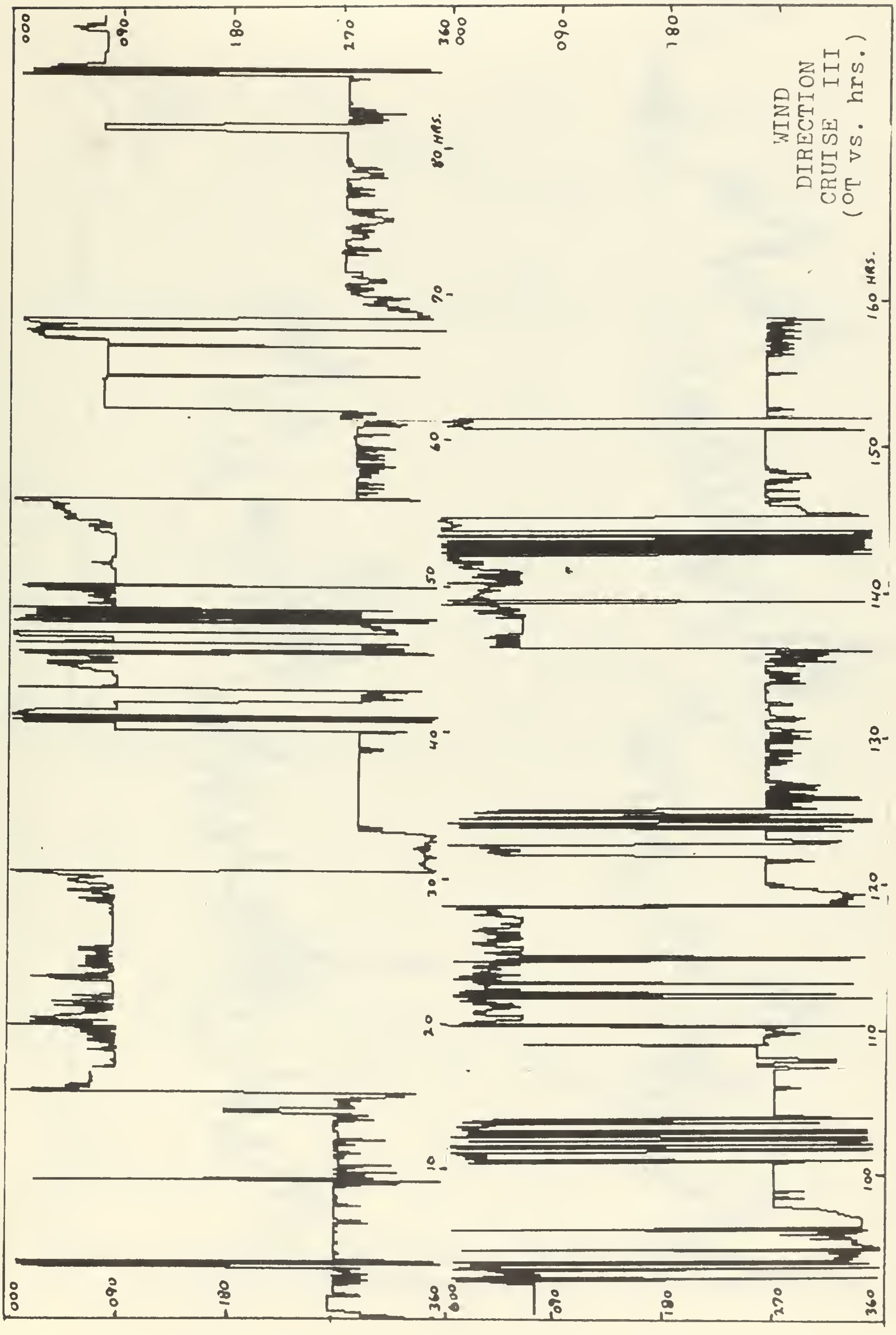

WIND
DIRECTION
CRUISE III
(°T vs. hrs.)
000
090
180
270
360
10
20
30
40
50
60
70
80 HRS.
100
110
120
130
140
150
160 HRS.

Figure 20.

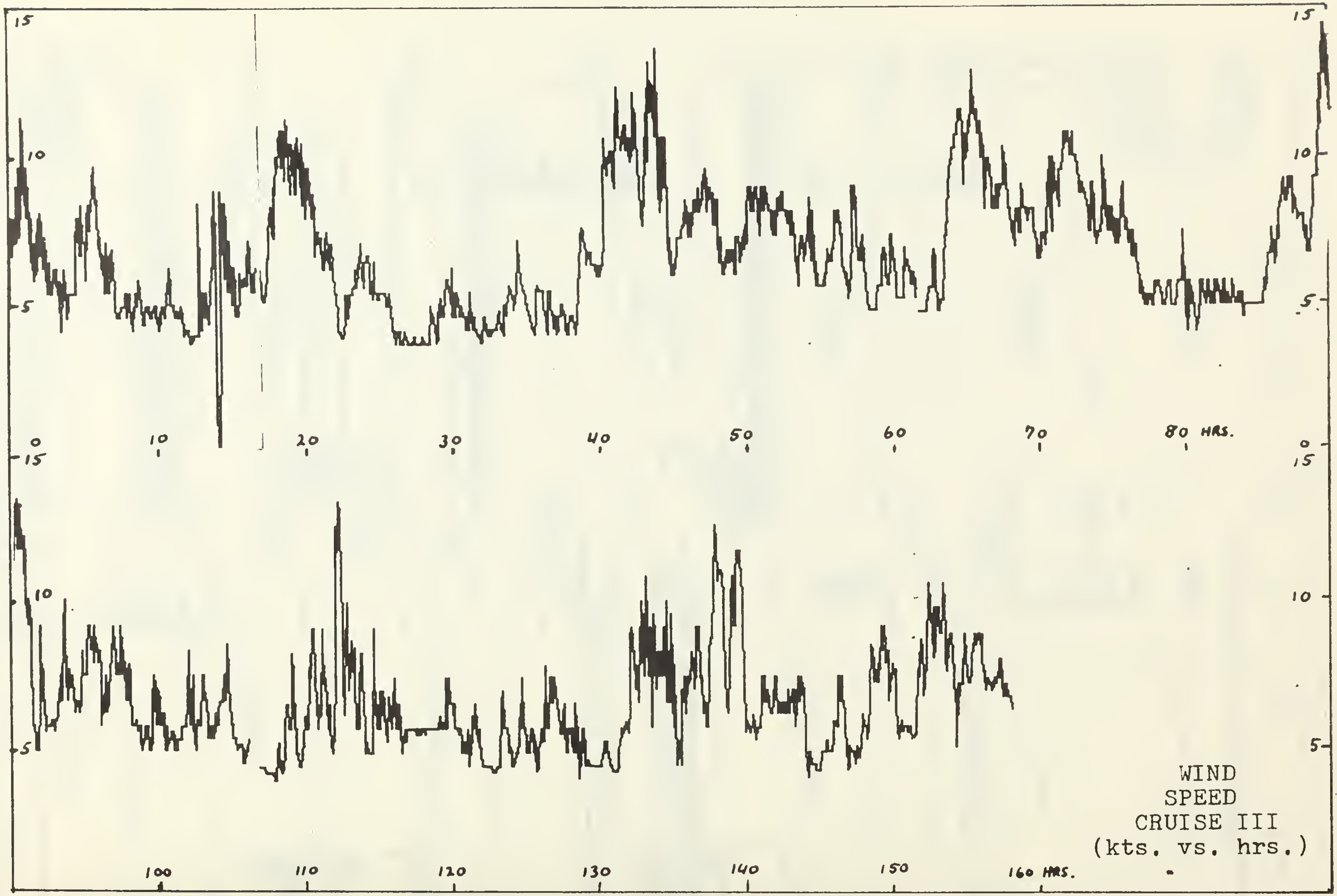


Figure 21.

Fig. 22. Power Spectra of Tide
(normalized energy density vs. period in hours)

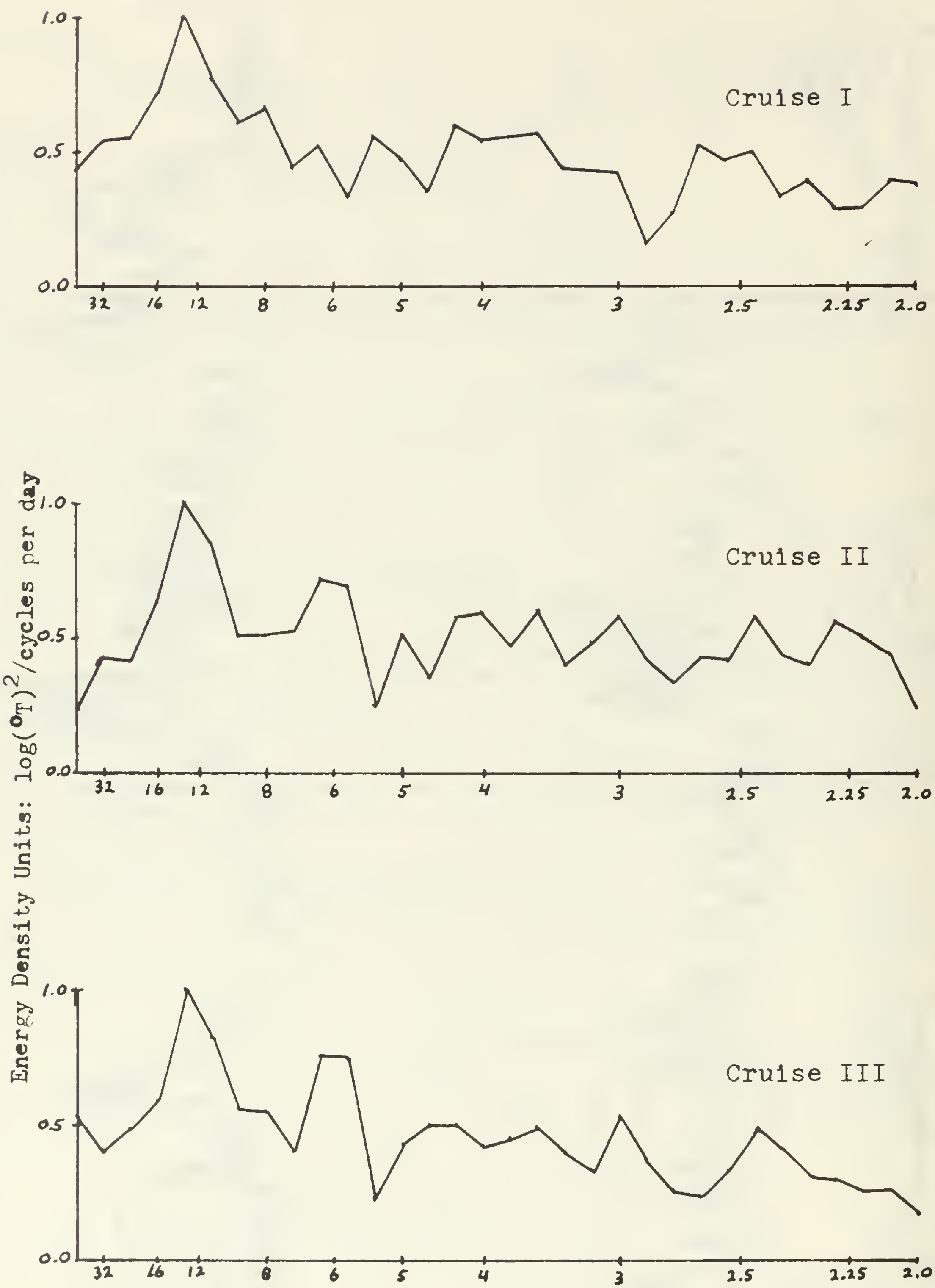


Fig. 23. Power Spectra of Current Direction
(normalized energy density vs. period in hours)

Fig. 24. Power Spectra of Current Speed
(normalized energy density vs. period in hours)

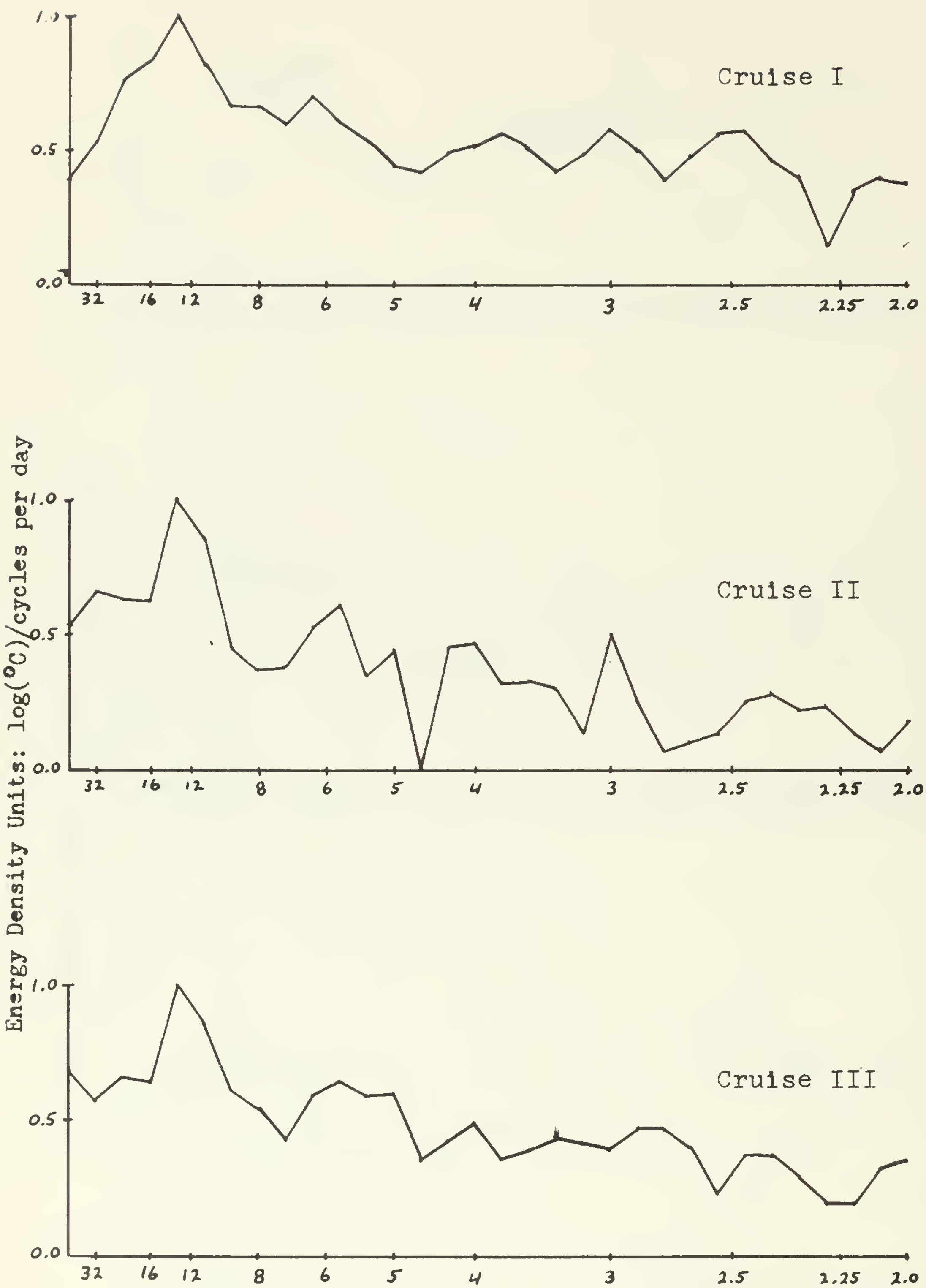


Fig. 25. Power Spectra of Water Temperature
(normalized energy density vs. period in hours)

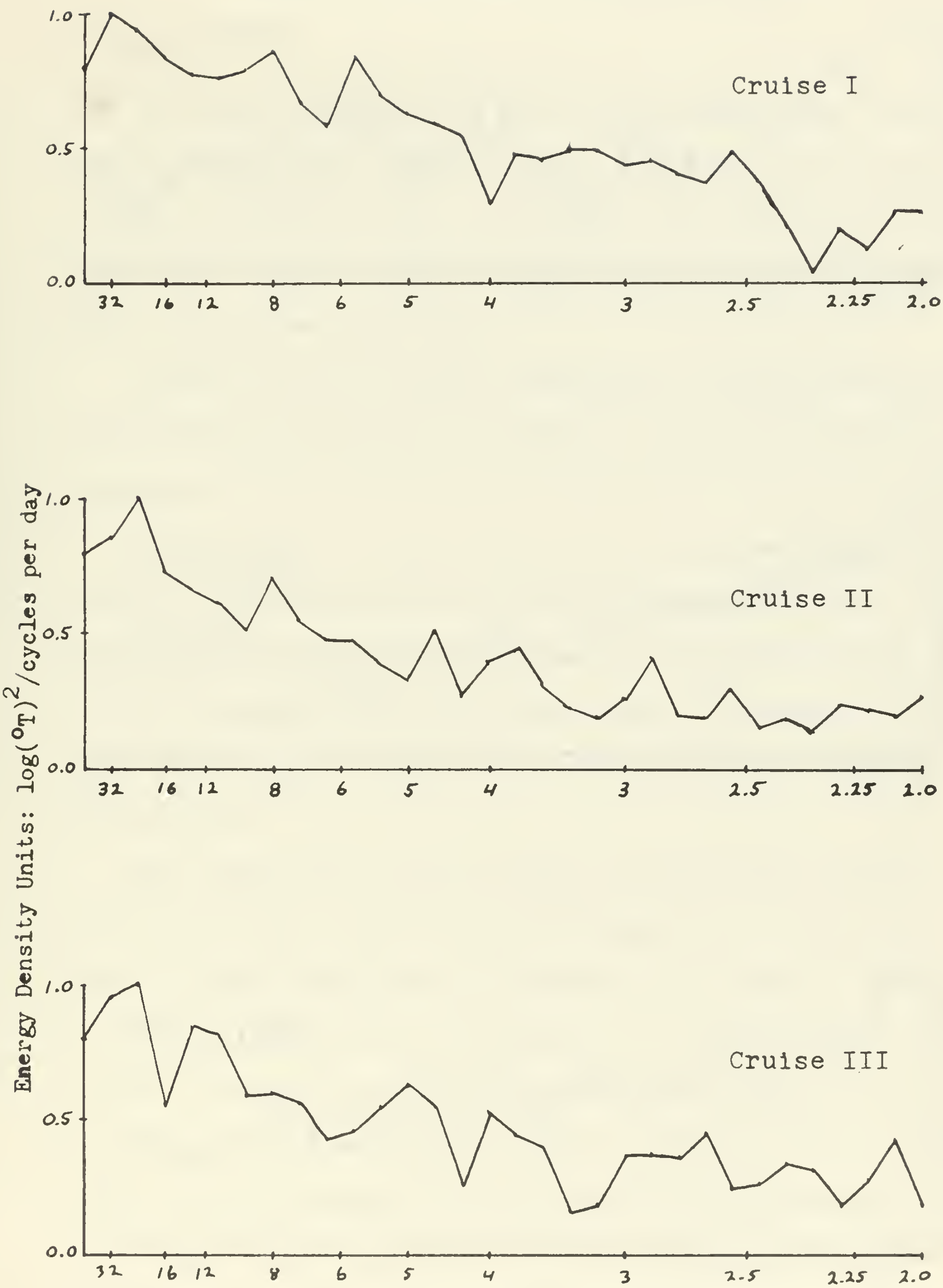


Fig. 26. Power Spectra of Wind Direction
(normalized energy density vs. period in hours)

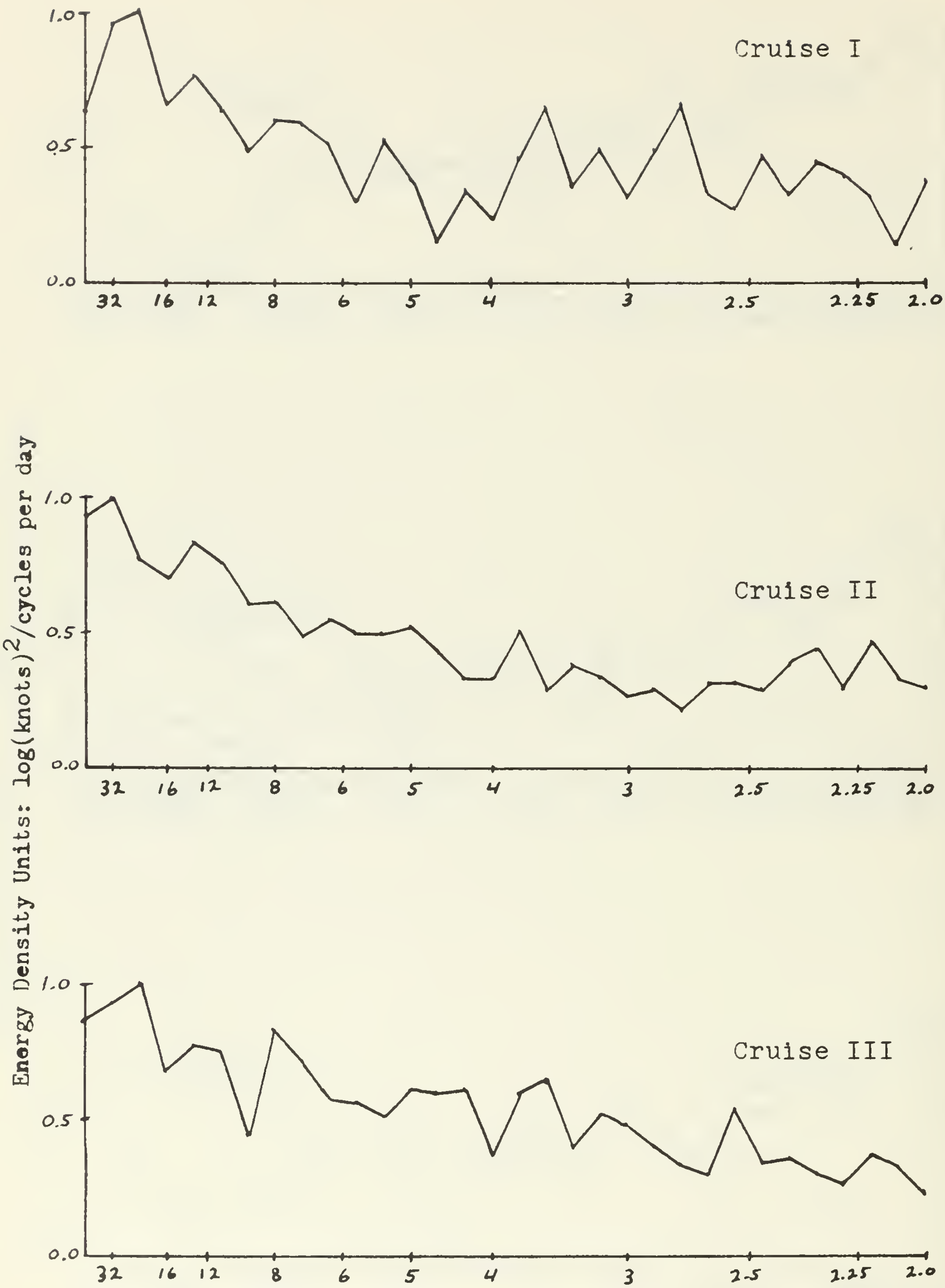


Fig. 27. Power Spectra of Wind Speed (normalized energy density vs. period in hours)

VI. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

A. SUMMARY

Continuous measurements of water temperature, current speed, and current direction were taken for three 7-day periods in the head of Monterey Submarine Canyon. The arrays were positioned along the canyon axis at 80, 90, and 110 fathoms, with the measuring system about 40 feet above the bottom.

Current flow was influenced predominantly by the canyon topography. The directional distribution was bimodal in the up and down-canyon directions.

Current speeds in excess of one knot were common throughout the records. The average speed was 0.58 knot (standard deviation: 0.28 knot) which is considerably higher than previously recorded values of current speeds in this or any other canyon. The range of the tide appears to have a direct influence on the maximum speed attained in each cycle.

Water temperature, current speed, and current direction all exhibited periodic fluctuations corresponding to the tidal cycle. Results of this investigation substantiate the findings of Gatje and Pizinger (1965) in that the reversal of the near-bottom current direction coincides closely with the times of high and low tide. And further, that the direction of flow is contrary to what would be expected, i.e., up-canyon on the falling tide and down-canyon on the rising tide. The down-canyon flow was generally of a greater magnitude and sustained for a longer time than was the up-canyon flow.

The temperature distribution shows a wider range of warmer temperatures for the last two cruises than for the first. Warmer water was associated with the seaward (down-canyon) current direction, while a reversal to up-canyon flow always resulted in a marked decrease in water temperature.

Spectral analysis failed to reveal any significant correlation between wind speed or direction and the current flow.

There appears to be a relationship between wave period and the maximum current speeds attained, however this was not investigated in detail and should be the object of future research.

B. CONCLUSIONS

The primary environmental factor influencing the near-bottom currents in Monterey Submarine Canyon is the semidiurnal tidal fluctuations.

The correlation between current direction and tidal phase is very good as long as the semidiurnal tidal components are nearly equal. When there is a mixed tide, the relationship becomes vague. However, as the tide returns to having equal semidiurnal variations, the relationship with current direction again becomes readily apparent.

The near-bottom currents may be explained as a seaward return flow of inshore water movement due to tide and wave/swell activity.

The periodic fluctuations of water temperature and current speed are probably directly related to the tidal cycle and are manifestations of the reversal of the current direction with change in the tidal phase.

C. RECOMMENDATIONS

Future current studies should be of a longer duration to allow greater resolution of the power spectrum calculations.

To better define the nature and extent of the near-bottom currents multiple arrays should be used in various configurations (e.g., two or more meters arranged vertically on a single moor, simultaneous moorings at different depths along the canyon axis, or one array in the canyon with another measuring water motion on the continental shelf nearby).

Present data should also be re-evaluated after filtering out tidal components to determine if there are other significant periods of oscillation, which may be obscured by the tidal influence.

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APPENDIX A

```
C. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
C
C     PROGRAM CURRENT
C
C         THIS PROGRAM PROVIDES ELEMENTARY STATISTICS FOR THREE TIME
C     SERIES OF CURRENT TEMPERATURE, SPEED, AND DIRECTION.  MEANS ARE
C     COMPUTED HOURLY, DAILY AND FOR THE ENTIRE SERIES.  A HISTOGRAM
C     IS PROVIDED DAILY AND FOR THE SERIES.  VARIANCE AND STANDARD
C     DEVIATION ARE COMPUTED FOR THE SERIES.  OPTIONAL GRAPHICAL OUTPUTS
C     HISTOGRAMS ARE PROVIDED.
C
C
      DIMENSION DATE(3),DATO(3),TIME(3000),T(3000),S(3000),D(3000),
     1M(3000)
      REAL LABEL/4H    /
C     IND=NUMBER OF DATA SETS
      IND=1
      DO 1313 III=1,IND
      CLOCK=ITIME(0)*0.01
C     CONTROL CARD INPUT:
      READ(5,202)NN,NO,NT,NA,NH,NP,PN,NW,PW,ICOR,IMO,DATE,DATO
C       NN=NO. OF DATA POINTS; CALL DRAW MUST BE ADJUSTED
C           TO TOTAL OF NN POINTS(I4)
C       NO=DAY OF FIRST OBSERVATION(I2)
C       NT=TIME OF FIRST OBSERVATION(I4)
C       NA=LARGEST NT LESS THAN 2400(I4)
C       NH=HOUR FRACTION(IN MIN.) OF FIRST OBS. (I2)
C       NP=LATITUDE DEGREES(I2)
C       PN=LATITUDE MINUTES (F6.2)
C       NW=LONGTITUDE DEGREES(I3)
C       PW=LONGTITUDE MINUTES(F6.2)
C       ICOR=DIRECTION CORR. FOR MAGNETIC VAR. OR DEV. (I3)
C       IMO=LAST DAY OF MONTH(I3)
C       DATE=MONTH OF OBSERVATION(3A4)
C       DATO=DATE PLUS ONE MONTH(3A4)
      DEL=3.75
C     DEL IS THE SAMPLING INTERVAL IN MINUTES
      TIME(1)=0.
      NODRW=0
C     NODRW=1 IF GRAPHS ARE NOT DESIRED
      L=0
      NZ=0
      IDAY=1
      WRITE(6,104)NP,PN,NW,PW,NO,NT,DATE
      WRITE(6,100)
      WRITE(6,106)NO,NT,DATE
C     INPUT TEMP, SPEED, AND DIRECTION TIME SERIES
      DO 5 I=1,NN,5
```

```
      READ(5,200,END=55)(T(I+K),S(I+K),M(I+K),K=0,4)
    5 CONTINUE
   55 CONTINUE
C     ADJUST DIRECTION IF REQUIRED
   41 DO 10 I=1,NN
      M(I)=M(I)+ICOR
      IF(M(I)-0.)42,43,43
   42 M(I)=M(I)+360
   43 CONTINUE
      N=I
      IF(T(I).EQ.1.)GO TO 10
    7 WRITE(6,101)TIME(I),T(I),S(I),M(I),I
      IF(L.LT.16)GO TO 8
      NT=NT+100
      IF(NT.LE.NA)GO TO 56
      NT=0000+NH
      NO=NO+1
      IMN=I-NZ
C     AT END OF EACH DAY COMPUTE STATISTICS
      CALL DAY(T,S,M,IMN,I,1,DTAV,DSAV,DDAV)
      IDDAV=IFIX(DDAV)
      WRITE(6,88)IDAY,DTAV,DSAV,IDDAV
   88 FORMAT(5X,'DAY ',I2,' STATISTICS:     AVGDAYTEMP=',F6.2,3X,
     1'AVGDAYSPD=',F5.2,3X,'AVGDAYDIR=',I4,//)
      IDAY=IDAY+1
   67 CONTINUE
      NZ=0
C     IF MONTH CHANGES REPLACE THE DATE
   56 IF(NO.LE.IMO)GO TO 3
      NO=1
      DO 60 J=1,3
   60 DATE(J)=DATO(J)
    3 CONTINUE
      HR = TIME (I)/60.
      IF(I.GE.18)GO TO 11
      IML=I-L
      GO TO 12
   11 CONTINUE
      IML=I-L+1
   12 CONTINUE
C     CALL SUBROUTINES FOR HOURLY MEANS
      CALL MEAN(T,IML,I,AT )
      CALL MEAN(S,IML,I,AS )
      CALL MEAND(M,IML,I,S,AVG)
      MD=IFIX(AVG)
      IF(MD.GE.0)GO TO 58
      MD=360+MD
   58 CONTINUE
```

```
C     WRITE OUT THE HOURLY MEANS
      WRITE (6,103) NO,NT,DATE,HR,AT,AS,MD
      L=0
    8 TIME(I+1)=TIME(I)+DEL
      NZ=NZ+1
      L=L+1
   10 CONTINUE
      N=NN
C     COMPUTE THE TIME SERIES MEANS
      CALL MEAN(T,1,N,TAT)
      CALL MEAN(S,1,N,TAS)
      CALL MEAND(M,1,N,S,AVG)
      MMD=IFIX(AVG)
      IF(MMD.GE.0)GO TO 57
      MMD=360+MMD
   57 CONTINUE
      WRITE(6,107)TAT,TAS,MMD
      DO 16 I=1,N
   15 D(I)=FLOAT(M(I))
   16 CONTINUE
C     CALL HISTO SUBROUTINE FOR TIME SERIES HISTOGRAM
      CALL HISTO(5.,16.,44,T,NN,1,NODRW)
      CALL HISTO(C.,1.,20,S,NN,1,NODRW)
      CALL HISTO(0.,360.,36,D,NN,1,NODRW)
C     CALL POWER SUBROUTINE FOR RMS,VARIANCE, AND STANDARD DEVIATIONS
      CALL POWER (DEL,NN,T,S,D,100)
      CLOCK=ITIME(0)*0.01-CLOCK
      WRITE(6,999)CLOCK
  105 FORMAT(6A8)
  202 FORMAT(I4,I2,2I4,2I2,F6.2,I3,F6.2,2I3,3A4,3A4)
  104 FORMAT(1H1,T40,'CURRENT DATA OBTAINED IN MONTEREY CANYON',///,5X,
     5'METER POSITION:  ',
     1I2,F6.2,' N  ',I3,F6.2,' W',/,5X,'ZERO TIME: ',I2,I4,'(LOCAL)',
     2 3A4,//,5X,'TIME IN MINUTES',/,5X,'TEMPERATURE IN DEGREES CENTIGRA
     3DE',/,5X,'CURRENT SPEED IN KNOTS ',/,5X,'CURRENT DIRECTION IN DEGR
     4EES TRUE',////)
  100 FORMAT(15X,'TIME',10X,'TEMPERATURE',6X,'CURRENT SPEED',
     14X,'CURRENT DIRECTION')
  106 FORMAT(1H0,5X,I2,I4,3A4)
  200 FORMAT(5(F5.1,F5.2,I4))
  101 FORMAT(     10X,F10.2,13X,F4.1,15X,F5.2,14X,I3,5X,I5)
  103 FORMAT(1H0,I3,I4,3A4,2X,F5.1,'HRS',4X,'MEAN TEMP:',
     1F6.2,4X,'MEAN SPEED:',F5.2,2X,'MEAN DIR:',I3,//)
  107 FORMAT(1H0,11X,'MEANS FOR THIS RECORD:   TEMP:',F6.2,2X,'SPEED:',
     1F5.2,2X,'DIRECTION:',I3)
  999 FORMAT(///,T80,'ELAPSED COMPUTING TIME=',F15.7,'SECONDS')
 1313 CONTINUE
      STOP
```

```
      END


      SUBROUTINE MEAN(A,J,M,AVG)
C     THIS SUBROUTINE COMPUTES THE ARITHMETIC MEAN OF
C     ANY INPUT PARAMETER.
      DIMENSION A(3000)
      AVG=0.0
      SUM=0.0
      KK=M-J+1
      FKK=FLOAT(KK)
      DO 1 K=J,M
    1 SUM=SUM+A(K)
      AVG=SUM/FKK
      RETURN
      END


      SUBROUTINE MEAND(LL,J,M,S,AVG)
C     THIS SUBROUTINE COMPUTES THE MEANS OF DIRECTIONS INPUT AS
C     COMPASS HEADINGS BY SUMMING SINES AND COSINES, CONVERT
C     TO VECTOR WITH SPEED, THEN NORMALIZE AND FIND THE
C     ARCTANGENT.  THIS PROCEDURE NECESSARY TO CIRCUMVENT THE
C     000 TO 360 DISCONTINUITY.
      DIMENSION LL(3000),S(3000)
      SUM1=0.0
      SUM2=0.0
      DO 1 K=J,M
      AK=LL(K)*0.01745329
      IML=M-J+1
      IF (S(K).GT.0.0) GO TO 13
C     SPEED NOT AVAILABLE. READ FROM DATA CARDS AS S(K)=0.0          I ONLY
C     INSERT FALSE VALUE TO ELIMINATE DIVISION BY ZERO.              I ONLY
      S(K)=0.001
   13 CONTINUE
      SUM1=SUM1+S(K)*SIN(AK)
      SUM2=SUM2+S(K)*COS(AK)
    1 CONTINUE
      U=SUM1/FLOAT(IML)
      V=SUM2/FLOAT(IML)
      USQ=U**2
      VSQ=V**2
      SUMSQ=USQ+VSQ
      VAVG=SQRT(SUMSQ)
```

```
      X=U/V
      AVG=ATAN2(U,V)
      AVG=AVG/.01745329
      RETURN
      END



      SUBROUTINE HISTO(A,Z,K,X,L,M,NODRW)
C     THIS SUBROUTINE OBTAINS HISTOGRAM, PERCENT OF DATA PER
C     INTERVAL, PROBABILITY DENSITY, AND PROBABILITY DISTRIBUTION.
C     ENTER WITH: A=LOWER BOUND
C                 Z=UPPER BOUND
C                 K=NO.INTERVALS(MAX=50)
C                 X=VARIABLE NAME
C                 L=NO.VARIABLES(MAX=3000)
C                 NODRW=1 (IF GRAPH NOT DESIRED)
      DIMENSION N(3000),X(3000),P(55),PP(55),D(55),PD(55),B(3000)
      REAL*8 ITITLA(12)
      REAL LABEL/4H    /
      IF(NODRW.EQ.1)GO TO 12
      READ(5,105)(ITITLA(I),I=1,12)
   12 CONTINUE
      WRITE(6,101)
      LL=0
      C=(Z-A)/FLOAT(K)
      D(1)=A
      KP1=K+1
      KP2=K+2
      DO 1 I=2,KP2
      IM1=I-1
    1 D(I)=A+IM1*C
      SUMP=0.0
      DO 5 I=1,KP2
    5 B(I)=0
      LLL=M+L
      DO 2 J=M,LLL
      DO 3 I=1,KP2
      IP1=I+1
      IF(X(J).LT.D(I))GO TO 3
      IF(X(J).GE.D(I))GO TO 4
    4 IF(X(J).LT.D(IP1))GO TO 10
      GO TO 3
   10 B(I)=B(I)+1.
      LL=LL+1
      IF(X(J).LE.Z)GO TO 3
      LL=LL-1
```

```
    3 CONTINUE
    2 CONTINUE
      DO 6  I=1,KP2
    6 P(I)=B(I)/FLOAT(LL)
      DO 7  I=1,KP2
    7 PP(I)=P(I)/C
      DO 8  I=1,KP2
      SUMP=SUMP+PP(I)
    8 PD(I)=SUMP*C
      DO 9  I=1,KP1
      IP1=I+1
      N(I)=IFIX(B(I))
      WRITE(6,100)I,D(I),D(IP1),N(I),P(I),PP(I),PD(I)
    9 CONTINUE
  101 FORMAT(1H0,10X,'INTERVAL',11X,'OCCURRENCES',3X,'% DATA',3X,
     1'DENSITY',3X,'DISTRIBUTION',//)
  100 FORMAT(4X,I2,F7.2,' - ',F7.2,4X,I8,3F12.3)
      WRITE(6,103)LL
  103 FORMAT(//,8X,'NUMBER OF POINTS :    ',I8)
  105 FORMAT(6A8)
      DO 11  I=1,KP1
   11 D(I)=D(I)+(C/2.)
      IF(NODRW.EQ.1)RETURN
      CALL DRAW(KP1,D,B,0,0,LABEL,ITITLA,0,0,0,C,0,0,9,7,0,LAST)
      RETURN
      END


      SUBROUTINE POWER (DEL,N,X,Y,Z,L)
C     THIS SUBROUTINE COMPUTES MEANS, MEAN SQUARED VALUES AND
C     STANDARD DEVIATIONS OF THREE INPUT TIME SERIES.
      DIMENSION XM(3000),X(3000),Y(3000),Z(3000)
C  ENTER WITH:      DEL=SAMPLING INTERVAL IN MINUTES
C                   N=NUMBER OF SAMPLES (MAX.=3000)
C                   X=VARIABLE OF THE FIRST SERIES
C                   Y=VARIABLE OF THE SECOND SERIES
C                   Z=VARIABLE OF THE THIRD SERIES
C                   L=NUMBER OF LAGS (MAX.=200)
C     CALCULATION OF SERIES MEAN VALUE
      SUM1=0.0
      SUM2=0.0
      SUM3=0.0
      DO 2  I=1,N
      SUM1=SUM1+X(I)
      SUM2=SUM2+Y(I)
    2 SUM3=SUM3+Z(I)
```

```
      XBAR=SUM1/N
      YBAR=SUM2/N
      ZBAR=SUM3/N
      WRITE(6,3)XBAR,YBAR,ZBAR
    3 FORMAT(T10,'SAMPLE MEANS:',//T35,'XBAR= ',F10.3,/,T35,'YBAR= ',
     1F10.3,/,T35,'ZBAR= ',F10.3,///)
C     TRANSFORMATION TO ZERO MEAN VALUE
      DO 4 I=1,N
      XM(I)=X(I)-XBAR
    4 CONTINUE
      CALL MEAN (XM,1,N,AVG)
      WRITE (6,15)AVG
      DO 44 I=1,N
      XM(I)=Y(I)-YBAR
   44 CONTINUE
      CALL MEAN (XM,1,N,AVG)
      WRITE (6,15)AVG
      DO 444 I=1,N
      XM(I)=Z(I)-ZBAR
  444 CONTINUE
      CALL MEAN (XM,1,N,AVG)
      WRITE (6,15)AVG
   15 FORMAT(T40,F30.10)
C     CALCULATION OF THE MEAN SQUARE VALUE
      SUM1=0.0
      SUM2=0.0
      SUM3=0.0
      DO 5 I=1,N
      SUM1=SUM1+(X(I)-XBAR)**2
      SUM2=SUM2+(Y(I)-YBAR)**2
      SUM3=SUM3+(Z(I)-ZBAR)**2
    5 CONTINUE
      XMS=SUM1/N
      YMS=SUM2/N
      ZMS=SUM3/N
      WRITE(6,6)XMS,YMS,ZMS
    6 FORMAT(T10,'MEAN SQUARE VALUES:',//,T35,'XMSQ= ',F10.3,/,T35,
     1'YMSQ= ',F10.3,/,T35,'ZMSQ= ',F10.3,///)
C     CALCULATION OF THE STANDARD DEVIATION
      XTEMP=SUM1/(N-1)
      YTEMP=SUM2/(N-1)
      ZTEMP=SUM3/(N-1)
      SX=SQRT(XTEMP)
      YX=SQRT(YTEMP)
      ZX=SQRT(ZTEMP)
      WRITE(6,7)SX,YX,ZX
    7 FORMAT(T10,'STANDARD DEVIATIONS:',//,T35,'XSTDDEV= ',F10.5,/,T35,
     1'YSTDDEV= ',F10.5,/,T35,'ZSTDDEV= ',F10.5,///)
```

```
      RETURN
      END


      SUBROUTINE DAY(T,S,M,J,K,NODRW,DTAV,DSAV,DDAV)
C     THIS SUBROUTINE UTILIZES PREVIOUS SUBROUTINES TO OBTAIN
C     DAILY STATISTICS.
      DIMENSION DH(3000),T(3000),S(3000),M(300C)
C     ENTER WITH:  T=TEMPERATURE SERIES
C                  S=SPEED SERIES
C                  M=DIRECTION SERIES
C                  J=DAY START OBSERVATION NUMBER
C                  K=TOTAL OBSERVATIONS IN THE SERIES
C                  NODRW=1 (IF GRAPH NOT DESIRED)
      CALL MEAN(T,J,K,DTAV)
      CALL MEAN(S,J,K,DSAV)
      CALL MEAND(M,J,K,S,DDAV)
      IF(DDAV.GE.0)GO TO 2
      DDAV=DDAV+360.
    2 CONTINUE
      JP1=J+1
      KK=K-JP1
      WRITE(6,3)JP1,K,KK
    3 FORMAT(2X,'DAILY HISTO FROM',I4,' TO ',I4,' TOTAL: ',I4,'PTS',//)
      DO 1 I=JP1,K
    1 DH(I)=FLOAT(M(I))
      CALL HISTO(5.,16.,44,T ,KK,J,NODRW)
      CALL HISTO(0.,1.,20,S ,KK,J,NODRW)
      CALL HISTO(0.,360.,36,DH,KK,J,NODRW)
      RETURN
      END
```

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13. ABSTRACT

Continuous bottom current measurements were taken in the head of Monterey Submarine Canyon in water depths ranging from 80 to 110 fathoms utilizing an in situ Savonius Rotor current measuring system placed approximately 40 feet above the bottom. Concurrent wind, wave, and tidal data were collected with the current measurements. Basic statistical parameters and power spectra were then computed for each time series obtained.

Current speeds in excess of one knot were measured, with the current direction being predominantly along the canyon axis. Water temperature, current speed and direction all exhibit cyclic fluctuations of a periodicity equal to that of the semidiurnal tide. Cold, high-speed currents flow up-canyon (landward) on the falling tide while warmer, slower currents flow down-canyon (seaward) on the rising tide. Wind and wave conditions do not appear to have any significant effects on the near-bottom currents.

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